

FINAL

Addendum to the Intrinsic Remediation Engineering Evaluation/Cost Analysis (EE/CA) for the Former AGE Fueling Facility Site



**Seymour Johnson Air Force Base
Goldsboro, North Carolina**

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FINAL

**ADDENDUM TO THE INTRINSIC REMEDIATION
ENGINEERING EVALUATION/COST ANALYSIS (EE/CA)
FOR THE FORMER AGE FUELING FACILITY SITE**

at

**SEYMOUR JOHNSON AIR FORCE BASE
GOLDSBORO, NORTH CAROLINA**

July 2001

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS**

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EXECUTIVE SUMMARY

This report presents the results of an addendum to the Intrinsic Remediation Engineering Evaluation/Cost Analysis (EE/CA) for the Former Aerospace Ground Equipment (AGE) Fueling Facility Site performed by Parsons Engineering Science (Parsons ES) at Seymour-Johnson Air Force Base (AFB), North Carolina (Parsons ES, 1996). The EE/CA was conducted to evaluate the use of intrinsic remediation with long-term monitoring (LTM) to address fuel-hydrocarbon-contaminated groundwater at the AGE Site. This addendum to the EE/CA summarizes the results of a groundwater sampling event conducted in April 2001 by the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection Division and Parsons ES. Results of this sampling event are used to evaluate spatial and temporal trends of groundwater contaminants at the AGE Site.

The Final EE/CA evaluated benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations, geochemical parameters, and biodegradation byproduct isopleth maps in order to determine the extent of contamination and the effect of natural attenuation on the dissolved BTEX plume. Additionally, the Final EE/CA modeled the dissolved BTEX plume migration over time using BIOPLUME II groundwater model code. Model results conservatively predicted that without source weathering or some form of engineered source reduction, the plume would expand approximately 200 to 250 feet in 10 years, then remain at steady-state indefinitely.

Modeling results of the Final EE/CA also indicated that dissolved BTEX contamination present in groundwater poses no significant risk to human health or the environment in its present, or predicted future, concentrations and distribution. Whether in conjunction with source reduction or as a sole remedial approach, intrinsic remediation with LTM is a viable option for remediating dissolved BTEX contamination found in shallow groundwater at this site.

Results of groundwater monitoring conducted from 1995 to 2001 indicate that natural attenuation of BTEX continues at the AGE Site. Based on the 10 micrograms per liter ($\mu\text{g/L}$) concentration isopleth, the extent of the BTEX plume has remained stable since the April 1995 sampling event. While the maximum BTEX concentration measured at the site decreased from 1995 to 2001, BTEX concentrations at 9 of 13 wells sampled increased. In addition, mobile LNAPL persists at the site as a continuing source of dissolved BTEX.

Geochemical indicators continue to support the occurrence of natural biodegradation at the site as evidenced by the distribution of electron acceptors and metabolic byproducts that are involved in biologically mediated reduction-oxidation (redox) reactions. The April 2001 geochemical data indicate that the groundwater environment is still reducing, and that the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis continue to be destructive attenuation mechanisms, especially within the core of the BTEX plume.

Comparison of the observed BTEX plume with simulated BIOPLUME II model plumes presented in the Final EE/CA indicates the no-source reduction model is overly conservative. The simulated BTEX plume for no-source reduction (Model SETUP16) predicted that total BTEX concentrations will remain above 12,000 µg/L indefinitely. Currently the highest BTEX concentration within the plume is at well MW-11 at 2,180 µg/L.

Continued long-term monitoring is recommended to evaluate the evolution of the dissolved BTEX plume and the ability of natural attenuation, microbially mediated biodegradation in particular, to stabilize and attenuate the contaminant plume. Annual groundwater monitoring is a sufficient frequency based on the stability of the BTEX plume. Additional downgradient well locations (past well MW-17) should be considered to evaluate potential expansion of the BTEX plume. Finally, free product at the site should be sampled and analyzed for BTEX. Results of this sampling could be combined with earlier sampling results to calculate a natural source weathering rate, which would allow more accurate model predictions for the persistence of the BTEX plume.

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence
AGE	Aerospace Ground Equipment
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CaCO ₃	calcium carbonate
CO ₂	carbon dioxide
DO	dissolved oxygen
EE/CA	Engineering Evaluation/ Cost Analysis
Fe ²⁺	ferrous iron
Fe ³⁺	ferric iron
ft/ft	foot per foot
ft/yr	feet per year
JP-4	jet petroleum
LIF	laser-induced fluorometry
LNAPL	light non-aqueous phase liquid
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mV	millivolts
NRMRL	National Risk Management Research Laboratory
ORP	oxidation-reduction potential
Parsons ES	Parsons Engineering Science, Inc.
redox	reduction-oxidation
SCAPS	Site Characterization and Analysis Penetrometer System
su	standard units
TEH	total extractable hydrocarbons
TMBs	trimethylbenzenes
TOC	total organic carbon
TVH	total volatile hydrocarbons
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UST	underground storage tank

1.0 INTRODUCTION

This addendum was prepared for the Technology Transfer Division, Air Force Center for Environmental Excellence (AFCEE/ERT) and Seymour Johnson Air Force Base (AFB) by Parsons Engineering Science, Inc. (Parsons ES) as an update to the *Intrinsic Remediation Engineering Evaluation/Cost Analysis for the Former AGE Fueling Facility Site, Seymour Johnson AFB, North Carolina* (Parsons ES, 1996). The Engineering Evaluation/Cost Analysis (EE/CA) was conducted to evaluate the use of intrinsic remediation with long-term monitoring (LTM) to address fuel-hydrocarbon-contaminated groundwater at the former Aerospace Ground Equipment (AGE) Fueling Facility Site (AGE Site). This addendum to the EE/CA summarizes the results of a groundwater sampling event conducted in April 2001 by the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection Division and Parsons ES.

1.1 Scope and Objective

The primary objective of this addendum is to evaluate changes in dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations, the extent of the BTEX plume, and the effectiveness of natural attenuation mechanisms to reduce BTEX concentration and mass over time. Data collected in April 2001 by the USEPA NRMRL and Parsons ES are used for evaluation of spatial and temporal trends of fuel hydrocarbons in groundwater. Results, calculations, and model predictions presented in the 1996 EE/CA (Parsons ES, 1996) are used as the basis for comparison.

1.2 Site Background

Seymour Johnson AFB is located near the city of Goldsboro, approximately 50 miles southeast of Raleigh, North Carolina, and primarily serves as the home of the Air Combat Command's 4th Fighter Wing. The Base is approximately 3,216 acres in area and is bounded on the southwest by the Neuse River, and on the northwest by Stoney Creek.

The former AGE fueling facility is located in the central portion of the Base, adjacent to Building 4715. The facility served as a fueling station for generators, tow trucks, and other support vehicles and equipment. In 1994 the fueling facility was taken out of service and the underground storage tanks (USTs), piping, and dispensers were removed. The site layout and the approximate former location of all the tanks is shown on Figure 1. The facility utilized three USTs for storage of various fuels, including one 2,000-gallon jet petroleum (JP-4) UST, one 2,000-gallon gasoline UST, and one 2,000-gallon diesel fuel UST. Soil and groundwater contamination were detected at the site during the excavation of the USTs in 1994. The contamination was attributed to leaks in the former fuel storage and distribution system.

Between January 19 and 25, 1995, Parsons ES and the United States Army Corps of Engineers (USACE) performed a preliminary screening of the subsurface conditions at the former AGE fueling facility. The USACE Site Characterization and Analysis Penetrometer System (SCAPS) truck was employed to perform laser-induced fluorometry (LIF), soil sampling, and installation of direct-push monitoring points. The preliminary

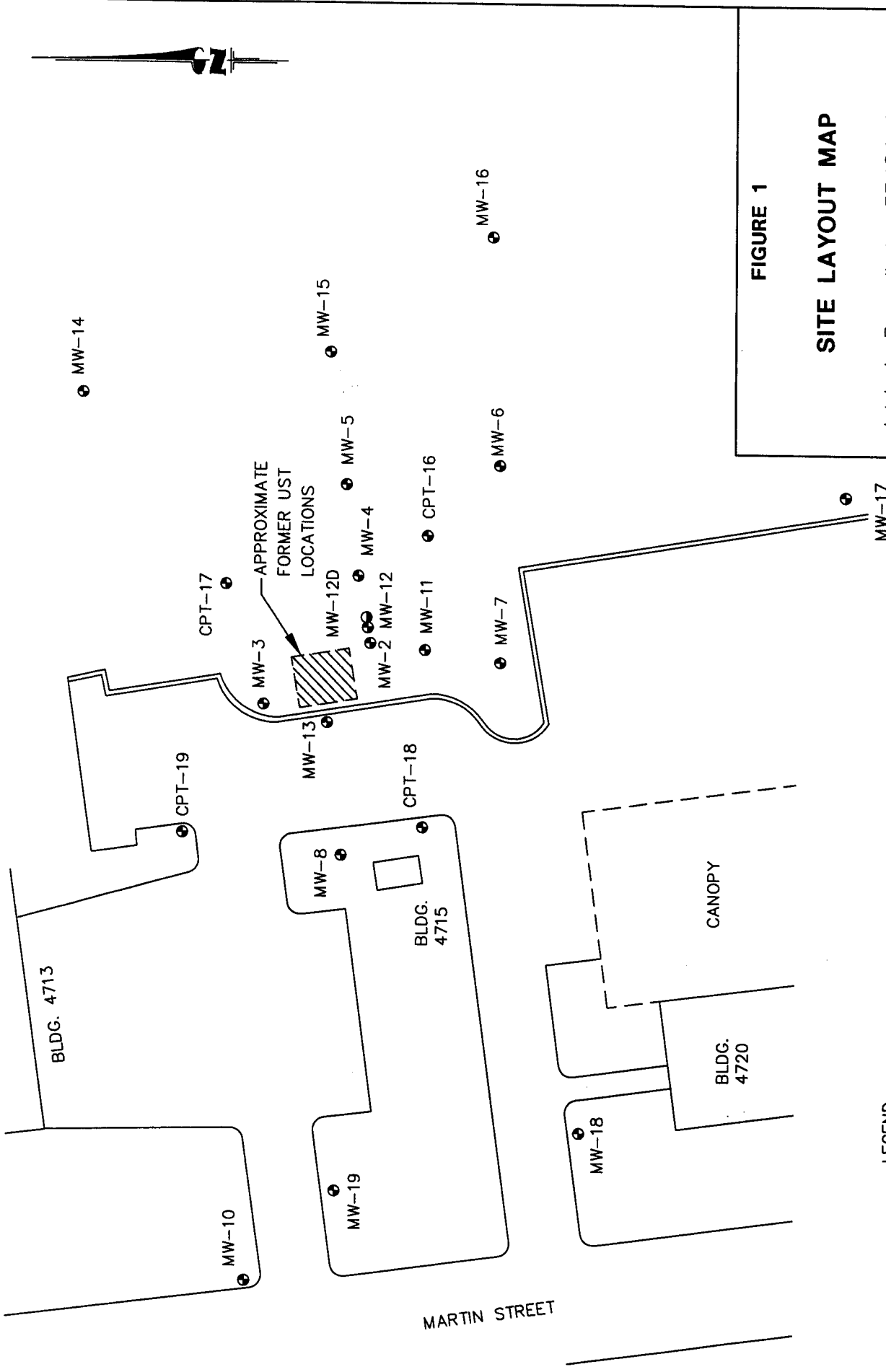


FIGURE 1

SITE LAYOUT MAP

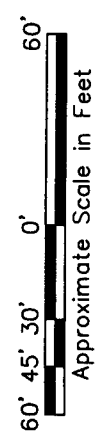
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Former AGE Fueling Facility
Seymour Johnson AFB, NC

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

LEGEND

- SHALLOW GROUNDWATER MONITORING POINT.
- DEEP GROUNDWATER MONITORING POINT.



screening provided data used to evaluate the extent of petroleum contamination in the subsurface, as well as site lithology. In April and July of 1995, Parsons ES conducted supplemental site characterization activities using an AFCEE Geoprobe® to collect soil and groundwater samples and to install additional monitoring points.

1.3 Overview of Proposed Remedial Approach

In the Final EE/CA (Parsons ES, 1996), comparison of BTEX; electron acceptor; and biodegradation byproduct isopleth maps for the AGE Site indicated strong qualitative evidence of biodegradation of BTEX compounds. Geochemical data strongly suggested that biodegradation of fuel hydrocarbons was occurring at the site via aerobic respiration and the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis. Patterns observed in the distribution of fuel hydrocarbons, electron acceptors, and biodegradation byproducts further indicated that biodegradation was reducing dissolved BTEX concentrations in site groundwater. Fate and transport modeling results suggested that dissolved BTEX would not reach potential exposure points at concentrations exceeding State of North Carolina groundwater quality standards.

Based on effectiveness, implementability, and cost, the remedial alternative recommended by the Air Force in the EE/CA for the AGE Site included mobile light non aqueous phase liquid (LNAPL) recovery, institutional controls, and LTM. Until 1996, base personnel used a bailer to remove between 0.25 and 0.5 gallon of LNAPL once a week from monitoring well MW-13. In 1996, all work at the AGE Site was suspended by an act of the North Carolina State legislature. The AGE Site remained closed until the North Carolina State legislature reopened the Site in 2000 and required a reassessment of the Site. Since the EE/CA, no additional site investigation or monitoring has occurred at the AGE Site until the April 2001 monitoring event.

2.0 MONITORING RESULTS

In April 2001, the USEPA NRMRL and Parsons ES measured groundwater and free product levels, and collected groundwater samples for field and fixed-base laboratory analysis from 13 monitoring points (MW-2, MW-3, MW-5, MW-6, MW-7, MW-8, MW-11, MW-15, MW-16, MW-17, MW-19, CPT-17, and CPT-19). Limited field and fixed-based laboratory analyses were collected at monitoring points MW-2 and CPT-16. Water and free product levels were measured for monitoring points MW-4, MW-10, MW-13, MW-14, MW-18, and CPT-16. Several wells near the source have well casings with inside diameters too small to admit an oil/water interface probe. Water levels were measured with a slimmer water level probe, and the presence of LNAPL was inferred from inspection of purge water.

Groundwater samples were analyzed in the field for dissolved oxygen (DO), temperature, conductivity, pH, oxidation-reduction potential (ORP), alkalinity, hydrogen sulfide, and ferrous iron (Fe^{2+}). Additional sample volume was analyzed, using fixed-base methods, for BTEX, trimethylbenzenes (TMBs), naphthalene, methane, sulfate, chloride, nitrate+nitrite (as nitrogen), ammonia, and total organic carbon (TOC). The analytical methods used for this sampling event are presented in Table 1. Copies of laboratory and field analytical results are provided in Appendix A.

TABLE 1
SUMMARY OF GROUNDWATER ANALYTICAL METHODS - APRIL 2001
INTRINSIC REMEDIATION EE/CA ADDENDUM
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Analyte	Method	Field (F) or Fixed-Base Laboratory (L)
Oxidation\Reduction Potential	Direct Reading Meter	F
Dissolved Oxygen	Direct Reading Meter	F
Conductivity	Direct Reading Meter	F
Temperature	Direct Reading Meter	F
pH	Direct Reading Meter	F
Ferrous Iron (Fe ²⁺)	Colorimetric, Hach Method 8146 or equivalent	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131 or equivalent	F
Alkalinity (Carbonate [CO ₃ ²⁻] and Bicarbonate [HCO ₃ ⁻])	Titrimetric, Hach Method 8221 or equivalent	F
Nitrate + Nitrite (as Nitrogen)	Lachat FIA Method 10-107-04-2-A	L
Ammonia	Lachat FIA Method 10-107-06-1-A	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
BTEX, TMBs, and Naphthalenes ^{a/}	RSKSOP-122 ^{b/} Revision 1	L
Methane	RSKSOP-175 and RSKSOP-194	L
Total Organic Carbon	RSKSOP-102	L

^{a/} BTEX = benzene, toluene, ethylbenzene, and xylenes, TMBs = Trimethylbenzenes.

^{b/} RSKSOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

2.1 Hydrogeology

The surficial sediments underlying the former AGE Fueling Facility consist of 5 to 10 feet of silty to sandy clay underlain by 5 to 10 feet of sand that coarsens with depth (Parsons ES, 1996). The upper unconfined aquifer occurs within these surficial sediments at approximately 10 to 13 feet below ground surface (bgs), and is approximately 5 to 8 feet thick. The upper clay strata of the Black Creek Formation acts as the basal confining unit for the surficial aquifer.

Table 2 lists groundwater elevations and measurable LNAPL thickness for the AGE Site. Groundwater elevation contour maps based on the results of the July 1995 and April 2001 sampling events are presented on Figure 2. The primary direction of groundwater flow is toward the southeast, although groundwater also flows to the south and southwest. Groundwater flow generally conforms to the surface topography at the site and may be influenced by impervious and uncovered areas and a storm water drainage swale located north of the site. Groundwater mounding in the location of the former USTs is evident and may be due to the higher permeability of the backfill material and the presence of a surface depression that acts as a local groundwater recharge area. Precipitation for the base is approximately 50 inches per year.

A comparison of the groundwater elevation measurements collected in July 1995 and April 2001 (Table 2 and Figure 2) shows a slight increase in groundwater elevations in April 2001 in comparison to the July 1995 sampling event. This increase in groundwater elevation is likely due to temporal fluctuations in the water table caused by infiltration of precipitation. As presented in the EE/CA, the spring season is characterized by heightened storm activity in comparison to the drier summer months. The temporal fluctuations do not appear to alter the primary flow direction at the site, as the flow remains southeast (Figure 2).

Law Environmental (1989 and 1992), calculated an average groundwater velocity of 91 feet per year (ft/yr) using an average hydraulic conductivity for the surficial aquifer measured at a site approximately 800 feet from the former AGE Site, an effective porosity of 0.3 foot per foot (ft/ft), and an observed site-wide hydraulic gradient of 0.005 ft/ft. No preferential contaminant migration pathways (such as utility trenches) were identified at the site.

The average hydraulic gradient calculated for April 2001 data was approximately 0.01 ft/ft, which is twice the gradient used by Law Environmental (1989 and 1992). Given an average hydraulic gradient of 0.01 ft/ft in 2001, an average advective groundwater velocity of 180 ft/yr was calculated for the site.

2.2 Sources of Contamination

During the site investigation conducted by Parsons ES in 1995, residual and free phase fuel was detected at the site. Mobile LNAPL is defined as the LNAPL that is free to flow in the aquifer and that will flow from the aquifer matrix under the influence of gravity. Mobile LNAPL was observed and measured in monitoring points MW-12 and MW-13

TABLE 2
GROUNDWATER ELEVATIONS AND LNAPL THICKNESS
INTRINSIC REMEDIATION EE/CA ADDENDUM
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	Date	Datum Elevation (ft amsl) ^{a/}	Well/Point Depth (feet)	Product Thickness (feet)	Depth to Groundwater (ft btoc) ^{b/}	Groundwater Elevation (ft amsl)
CPT-16	Apr-95	98.76	14.45	0.00	12.58	86.18
	May-95	98.76	14.45	0.00	12.86	85.90
	Jul-95	98.76	14.45	NM ^{c/}	12.30	86.46
	Apr-01	98.76	14.45	NM	12.32	86.44
CPT-17	Apr-95	97.37	14.62	0.00	10.73	86.64
	May-95	97.37	14.62	0.00	10.90	86.47
	Jul-95	97.37	14.62	NM	10.26	87.11
	Apr-01	97.37	14.62	NM	9.76	87.61
CPT-18	Apr-95	98.11	14.55	0.00	11.39	86.72
	May-95	98.11	14.55	0.00	11.55	86.56
	Jul-95	98.11	14.55	NM	11.65	86.46
CPT-19	Apr-95	96.86	14.80	0.00	11.78	85.08
	May-95	96.86	14.80	0.00	11.85	85.01
	Jul-95	96.86	14.80	NM	11.89	84.97
	Apr-01	96.86	14.80	NM	9.09	87.77
MW-2	Apr-95	97.76	11.55	NM	10.72	87.04
	May-95	97.76	11.55	NM	9.98	87.78
	Jul-95	97.76	11.55	NM	10.26	87.50
	Apr-01	97.76	11.55	0.00	9.69	88.07
MW-3	Apr-95	96.78	11.30	0.00	9.69	87.09
	May-95	96.78	11.30	0.00	9.86	86.92
	Jul-95	96.78	11.30	NM	9.18	87.60
	Apr-01	96.78	11.30	0.00	8.69	88.09
MW-4	Apr-95	98.44	14.43	0.00	11.93	86.51
	May-95	98.44	14.43	0.00	12.23	86.21
	Jul-95	98.44	14.43	NM	11.55	86.89
	Apr-01	98.44	14.43	1.25	12.40	87.04 ^{d/}
MW-5	Apr-95	97.93	13.52	0.00	11.80	86.13
	May-95	97.93	13.52	0.00	12.07	85.86
	Jul-95	97.93	13.52	NM	11.49	86.44
	Apr-01	97.93	13.52	0.00	11.12	86.81

TABLE 2 (Continued)
GROUNDWATER ELEVATIONS AND LNAPL THICKNESS
INTRINSIC REMEDIATION EE/CA ADDENDUM
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	Date	Datum Elevation (ft amsl) ^{a/}	Well/Point Depth (feet)	Product Thickness (feet)	Depth to Groundwater (ft btoc) ^{b/}	Groundwater Elevation (ft amsl)
MW-6	Apr-95	98.22	15.80	0.00	12.40	85.82
	May-95	98.22	15.80	0.00	12.67	85.55
	Jul-95	98.22	15.80	NM	12.28	85.94
	Apr-01	98.22	15.80	NM	11.95	86.27
MW-7	Apr-95	98.64	15.10	0.00	12.64	86.00
	May-95	98.64	15.10	0.00	12.91	85.73
	Jul-95	98.64	15.10	NM	12.36	86.28
	Apr-01	98.64	15.10	Sheen ^{d/}	12.34	86.30
MW-8	Apr-95	97.98	12.71	0.00	11.09	86.89
	May-95	97.98	12.71	0.00	11.16	86.82
	Jul-95	97.98	12.71	NM	10.58	87.40
	Apr-01	97.98	12.71	NM	10.30	87.68
MW-9	Apr-95	99.23	9.56	0.00	Dry	<89.67 ^{e/}
	May-95	99.23	9.56	0.00	Dry	<89.67
	Jul-95	99.23	9.56	NM	Dry	<89.67
MW-10	Apr-95	98.08	12.11	0.00	11.03	87.05
	May-95	98.08	12.11	0.00	11.03	87.05
	Jul-95	98.08	12.11	NM	10.54	87.54
	Apr-01	98.08	12.11	NM	10.43	87.65
MW-11	Apr-95	98.52	15.73	0.00	12.13	86.39
	May-95	98.52	15.73	0.00	12.38	86.14
	Jul-95	98.52	15.73	NM	11.78	86.74
	Apr-01	98.52	15.73	Sheen ^{d/}	11.45	87.07
MW-12	Apr-95	98.57	12.82	Sheen	12.20	86.37
	May-95	98.57	12.82	0.01	12.30	86.28 ^{d/}
	Jul-95	98.57	12.82	NM	11.62	86.95
	Apr-01	98.57	12.82	0.01	11.41	87.17 ^{d/}
MW-12D	Apr-95	NA	17.00	0.00	NM	NM
	May-95	NA	17.00	0.00	NM	NM
	Jul-95	NA	17.00	NM	NM	NM
MW-13	Apr-95	96.64	11.25	0.53	10.43	86.63 ^{d/}
	May-95	96.64	11.25	1.19	10.44	87.15
	Jul-95	96.64	11.25	NM	NM	NM
	Apr-01	96.64	11.25	0.12	8.91	87.83 ^{d/}

TABLE 2 (Continued)
GROUNDWATER ELEVATIONS AND LNAPL THICKNESS
INTRINSIC REMEDIATION EE/CA ADDENDUM
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	Date	Datum Elevation (ft amsl) ^{a/}	Well/Point Depth (feet)	Product Thickness (feet)	Depth to Groundwater (ft btoc) ^{b/}	Groundwater Elevation (ft amsl)
MW-14	Jul-95	98.99	10.50	NM	12.29	86.70
	Apr-01	98.99	10.50	NM	10.99	88.00
MW-15	Jul-95	99.66	13.00	NM	13.58	86.08
	Apr-01	99.66	13.00	NM	13.05	86.61
MW-16	Jul-95	98.08	12.00	NM	12.65	85.43
	Apr-01	98.08	12.00	NM	12.10	85.98
MW-17	Jul-95	97.38	15.00	NM	12.01	85.37
	Apr-01	97.38	15.00	NM	12.11	85.27
MW-18	Jul-95	98.34	15.00	NM	11.89	86.45
	Apr-01	98.34	15.00	NM	11.99	86.35
MW-19	Jul-95	98.13	14.00	NM	11.08	87.05
	Apr-01	98.13	14.00	NM	11.01	87.12

^{a/} ft amsl = feet above mean sea level.

^{b/} ft btoc = feet below top of casing.

^{c/} NM = not measured.

^{d/} Groundwater elevation corrected for the presence of LNAPL using a specific gravity of LNAPL of 0.8.

^{e/} LNAPL was not measured with an oil/water interface probe because the well diameter was too small to admit the probe.
Sheen was observed on accumulated purge water.

^{f/} Groundwater is located at an elevation below the bottom of the well.



and was suspected to be present in monitoring points MW-2 and MW-4. The inferred extent of mobile LNAPL in 1995 is shown on Figure 2.

Results of the sampling efforts conducted in April 2001 indicated that the extent on the mobile LNAPL had migrated slightly downgradient toward monitoring points MW-11 and MW-7 (Figure 2). Mobile LNAPL at monitoring point MW-4 increased from a detectable sheen to a product thickness of 1.25 feet. On the upgradient side of the former UST location, the product thickness at monitoring point MW-13 decreased from 1.19 feet measured in May 1995 to 0.12 feet in April 2001. These data suggest the bulk of the mobile LNAPL plume has migrated from the vicinity of MW-13 towards MW-4.

Residual LNAPL is defined as the LNAPL that is trapped in subsurface material by cohesive and capillary forces, and therefore will not flow through the aquifer matrix into a well under the influence of gravity. Residual hydrocarbon contamination resulting from vertical and lateral migration of free and dissolved hydrocarbons was detected over an area slightly more extensive than the mobile LNAPL plume at the AGE Site. During the April 1995 sampling event, 18 soil samples were collected from 12 locations and analyzed for BTEX using USEPA Method SW8020 to define the extent of residual LNAPL contamination. BTEX concentrations in soil ranged from 0.7 micrograms per kilogram ($\mu\text{g/kg}$) to 953,000 $\mu\text{g/kg}$, and were highest in samples collected near the capillary fringe. The area of soil contamination was approximately 100 feet by 60 feet. The areal extent of the residual soil contamination was similar to the areal extent of mobile LNAPL contamination, as shown on Figure 2.

In addition, soil samples were analyzed for total volatile hydrocarbons (TVH) and total extractable hydrocarbons (TEH) by USEPA Method SW8015 (modified). Results of TVH and TEH analyzes correlated well with BTEX results. TVH concentrations at the AGE Site ranged from less than 0.110 milligrams per kilogram (mg/kg) to 6,600 mg/kg . TEH concentrations ranged from less than 11 mg/kg to 4,800 mg/kg .

2.3 Total BTEX in Groundwater

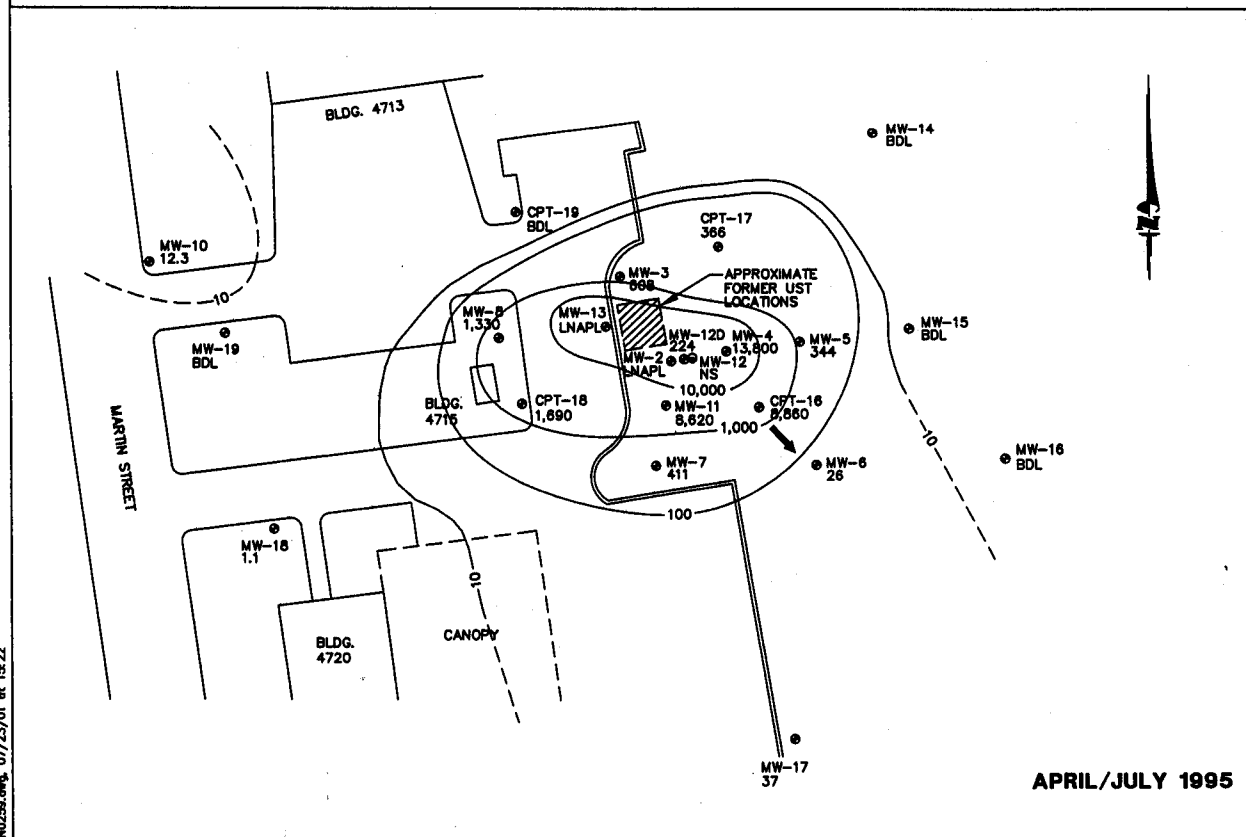
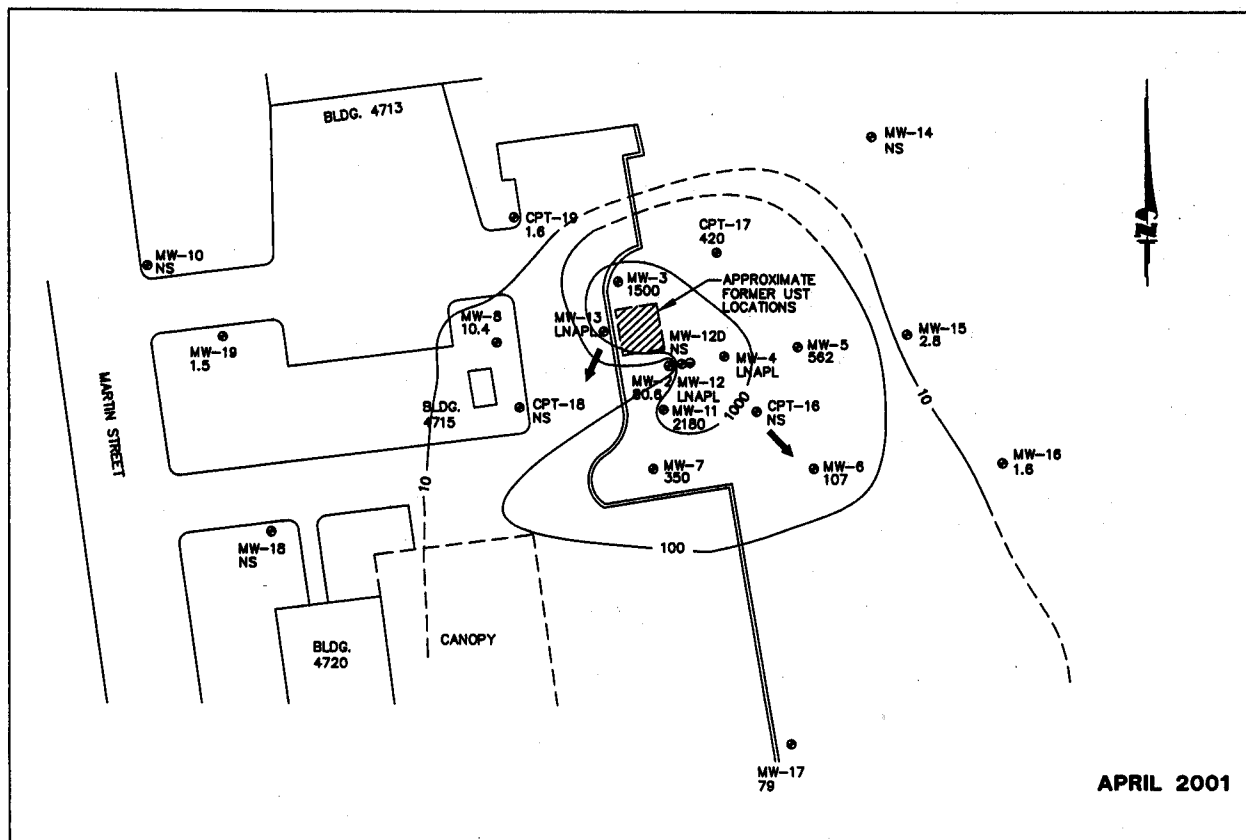
BTEX compounds were detected at measurable concentrations in groundwater samples from all 13 of the monitoring wells included in the April 2001 sampling event. BTEX concentrations in groundwater are summarized in Table 3. In order to evaluate trends in BTEX concentrations and distribution through time, the areal distributions of total BTEX in shallow groundwater for April/July 1995 and April 2001 are presented on Figure 3. The primary direction of dissolved BTEX migration at the AGE Site is inferred to be to the south and southeast, consistent with the primary direction of groundwater flow. Based on the distribution of total BTEX presented on Figure 3, the extent of the BTEX plume has increased slightly and migrated to the east, southeast, and south since the last sampling event in April/July 1995. In 1995 the dissolved BTEX plume, as inferred by the 10 microgram per liter ($\mu\text{g/L}$) isopleth was approximately 315 feet long. In the primary direction of flow, the plume extends approximately 260 feet downgradient from the source area. Because the aquifer is thin throughout and mounds in the vicinity of the source area, diffusion and density-driven flow of mobile LNAPL likely have been important factors in the distribution of BTEX contamination from the UST release.

TABLE 3
FUEL HYDROCARBONS DETECTED IN GROUNDWATER
INTRINSIC REMEDIATION EFCA APPENDIX
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	Date	Benzene (ug/L) ^a	Toluene (ug/L)	Ethylbenzene (ug/L)	p-Xylene (ug/L)	m-Xylene (ug/L)	o-Xylene (ug/L)	Total Xylenes (ug/L)	Total BTEX ^a (ug/L)	Naphthalene (ug/L)	1,3- Dimethylbenzene (ug/L)	1,2,4- Trimethylbenzene (ug/L)	1,2,3- Trimethylbenzene (ug/L)	Total Triethyl- benzenes (ug/L)	Total Volatile Hydrocarbons (ug/L) ^a	Total Extractable Hydrocarbons (ug/L)
MW-2	10-Apr-01	27.5	22.1	4.1	3.9	10.0	12.0	25.9	80.6	1.9	<0.5	2.9	1.0	3.9	— ^b	—
MW-3	18-Apr-95	280 B ^c	18	140	NR ^d	NR	NR	170 B	608	—	NR	NR	NR	75.5	3.2	2.61 ^e
MW-4	10-Apr-01	217	73.1	335	247	302	303	852	1,500	117	72.2	196	75.9	344	—	—
MW-4 (DUP) ^f	18-Apr-95	2,100	3,100	980	NR	NR	NR	6,400	12,600	—	NR	NR	NR	1,200	17	8.2
MW-5	18-Apr-95	2,300	3,300	1,100	NR	NR	NR	7,100	13,800	—	NR	NR	NR	1,470	17	7.3
MW-5	10-Apr-01	556	2.9	<0.5	<0.5	<0.5	3.3	3.3	562	77.3	4.1	<0.5	<0.5	4.1	—	—
MW-6	17-Apr-95	25	1.0	<0.4	NR	NR	NR	<0.4	26.0	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-6	09-Apr-01	106	1.0	<0.5	<0.5	<0.5	<0.5	ND ^g	107	2.7	<0.5	<0.5	<0.5	ND	—	—
MW-7	17-Apr-95	180	11	120	NR	NR	NR	100	411	—	NR	NR	NR	463	<0.1	0.6
MW-7	09-Apr-01	349	<1.0	<0.5	<0.5	<0.5	1.2	1.2	350	43.2	<0.5	6.4	3.6	10	—	—
MW-8	18-Apr-95	410	120	260	NR	NR	NR	540	1,390	—	NR	NR	NR	303	2.4	2.51
MW-8	09-Apr-01	104	<0.5	<0.5	<0.5	<0.5	<0.5	ND	10.4	9.5	<0.5	2.4	<0.5	2.4	—	—
MW-10	17-Apr-95	<0.4	5.3	2.6	NR	NR	NR	4.4	12.3	—	NR	NR	NR	9.7	<0.1	<0.5
MW-11	17-Apr-95	2,300 J	2,000 J	620	NR	NR	NR	3,700 J	8,620	—	NR	NR	NR	903 J	18	5.2
MW-11	10-Apr-01	993	633	108	70.1	187	193	450	2,180	<1.0	6.2	5.4	<0.5	11.6	—	—
MW-12D	18-Apr-95	110	40	12	NR	NR	NR	62	224	—	NR	NR	NR	20.7	0.2	0.5
MW-13 (LNAPL) ^f	18-Apr-95	1,000,000	3,300,000	2,300,000	NR	NR	NR	7,300,000	14,100,000	—	NR	NR	NR	10,000,000	NA	NA
MW-14	10-Jul-95	<0.4	<0.4	<0.4	NR	NR	NR	<0.4	ND	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-15	10-Jul-95	<0.4	<0.4	<0.4	NR	NR	NR	<0.4	ND	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-15	10-Apr-01	1.0	1.8	<0.5	<0.5	<0.5	<0.5	ND	2.8	1.5	<0.5	<0.5	<0.5	ND	—	—
MW-16	01-Apr-01	<1.0	1.6	<0.5	<0.5	<0.5	<0.5	ND	1.6	1.5	<0.5	<0.5	<0.5	ND	<0.1	<0.5
MW-17	10-Jul-95	37	<0.4	<0.4	NR	NR	NR	<0.4	37	—	<0.4	<0.4	<0.4	ND	0.1	<0.5
MW-17 (DUP)	09-Apr-01	77.6	1.2	<0.5	<0.5	<0.5	<0.5	ND	79	2.9	<0.5	<0.5	<0.5	ND	—	—
MW-17	09-Apr-01	77.5	1.3	<0.5	<0.5	<0.5	<0.5	ND	79	3.3	<0.5	<0.5	<0.5	ND	—	—
MW-18	10-Jul-95	<0.4	<0.4	<0.4	NR	NR	NR	1	1	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-18 (DUP)	10-Jul-95	<0.4	1.1	<0.4	NR	NR	NR	<0.4	1.1	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-19	10-Jul-95	<0.4	<0.4	<0.4	NR	NR	NR	<0.4	ND	—	NR	NR	NR	<0.4	<0.1	<0.5
MW-19	09-Apr-01	<1.0	1.5	<0.5	<0.5	<0.5	<0.5	ND	1.5	1.2	<0.5	<0.5	<0.5	ND	—	—
CFT-16	17-Apr-95	2,100	2,100	560	NR	NR	NR	4,100	8,860	—	NR	NR	NR	960	14	14
CFT-17	18-Apr-95	<61	18	88	NR	NR	NR	260	366	—	NR	NR	NR	68	1.8	1.31
CFT-17	10-Apr-01	84.5	4.7	164	108	132	45.4	167	420	44.3	<0.5	<1.0	<0.5	ND	—	—
CFT-18	18-Apr-95	820	200	170	NR	NR	NR	500	1,690	—	NR	NR	NR	366	2.8	1.8
CFT-19	18-Apr-95	<0.4	<0.4	<0.4	NR	NR	NR	<0.4	<0.4	—	NR	NR	NR	<0.4	<0.1	<0.5
CFT-19	10-Apr-01	<1.0	1.6	<0.5	<0.5	<0.5	<0.5	ND	1.6	2.1	<0.5	<0.5	<0.5	ND	—	—

^a BTEX = benzene, toluene, ethyl benzene, and xylene.
^b ug/L = micrograms per liter.
^c ug/L = milligrams per liter.
^d NR = indicates the compound was not analyzed for.
^e ND = indicates the compound was not detected at or above the detection limit.
^f LNAPL = light nonaqueous-phase liquid (mobile fluid product).
^g B = Compound detected in laboratory blank.

^a NR = indicates the concentration for the compound was not reported.
^b J = Indicates an estimated value.
^c DUP = Indicates a duplicate sample.
^d ND = Indicates that the compound was not detected at or above the detection limit.
^e LNAPL = light nonaqueous-phase liquid (mobile fluid product).



LEGEND

- SHALLOW GROUNDWATER MONITORING POINT.
- DEEP GROUNDWATER MONITORING POINT.
- BDL BELOW DETECTION LIMIT.
- ~100~ MOBILE LIGHT NONAQUEOUS-PHASE LIQUID.
- ISOPLETH OF EQUAL CONCENTRATION, DASHED WHERE INFERRED.
- ➔ DIRECTION OF GROUNDWATER FLOW.
- 366 TOTAL BENZENE, TOLUENE, ETHYLBENZENE, AND XYLENES (BTEX) IN GROUNDWATER (μg/L).
- NS NOT SAMPLED

60' 45' 30' 0 60'

Approximate Scale in Feet

FIGURE 3

TOTAL BTEX ISOPLETH

MAP FOR GROUNDWATER

APRIL/JULY 1995 AND APRIL 2001

Intrinsic Remediation EE/CA Addendum
Former AGE Fueling Facility
Seymour Johnson AFB, NC

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Of the 13 wells sampled in April 2001, total BTEX concentrations decreased in three wells and increased in nine wells. Total BTEX increased significantly in wells MW-3 and MW-6. Monitoring point MW-3 is located near the former UST location, in the center of the plume. Monitoring point MW-6 is located downgradient of the BTEX plume. Based on the 10 µg/L total BTEX concentration isopleth presented on Figure 3, the BTEX plume appears relatively stable. However, the increase in total BTEX at monitoring point MW-6 indicates that the core of the total BTEX plume is migrating slightly southeast. The detection of total BTEX in monitoring points MW-15 and MW-16, and the increase in total BTEX concentration at MW-17, MW-19, and CPT-19, all of which are located along the fringe of the BTEX plume, indicate that the BTEX plume is expanding at low levels (less than 5 µg/L).

Decreases in BTEX concentrations from 1995 to 2001 were observed at wells MW-7, MW-8, and MW-11 (Table 3). Significant decreases in BTEX concentrations (>1000 µg/L) were observed in wells MW-8 and MW-11. Well MW-8, located directly west of the former UST location, decreased in concentration from 1,330 µg/L in April 1995 to 10.4 µg/L in April 2001 (Figure 3). Similarly, well MW-11, located in the AGE source area, decreased in BTEX concentration from 8,620 µg/L in April 1995 to 2,180 µg/L in April 2001 (Figure 3). The decrease in BTEX concentrations at these wells located at the source areas indicates that while BTEX concentrations may have increased within the core of the plume, natural attenuation processes are occurring and acting to control the extent of the BTEX plume.

Comparison of the observed BTEX plume with simulated BIOPLUME II model plumes presented in the Final EE/CA indicates the models are not representative of current site conditions. The simulated BTEX plume for no source reduction (Model SETUP16) predicts that total BTEX concentrations will remain above 12,000 µg/L indefinitely. The maximum BTEX concentration observed in 2001 was 2,180 at well MW-11. The simulated BTEX plume for total source reduction over 5 years (Model SR5) predicts that total BTEX concentrations will decrease to 3,000 µg/L by 2002, with some expansion of the BTEX plume. While this is similar to the observed 2001 BTEX plume, the continued presence of LNAPL at the site is not duplicated in the model, as the total source is simulated to be removed by 2010. The observed data suggests that a reasonable rate of natural source weathering was not simulated in the model SETUP16 predictions. The similarity of current conditions to Model SR5 conditions suggests that the rate of natural weathering of the source and biodegradation of dissolved contamination is significant. Although a continuing source (LNAPL) persists at the AGE Site, natural attenuation alone has controlled and limited the migration and expansion of the BTEX plume.

2.4 Benzene in Groundwater

Of the four compounds that comprise BTEX, benzene is the primary risk driver at the AGE Site due to its higher chemical toxicity and corresponding lower regulatory action concentration. Table 3 summarizes the benzene concentrations in groundwater at the AGE Site. Groundwater samples collected from 13 of the site monitoring wells sampled during site investigation activities in 1995 had benzene concentrations above the North Carolina groundwater standard of 1 µg/L. Where detected, benzene concentrations

ranged from 25 µg/L to 2,300 µg/L. Table 3 shows that benzene concentrations have decreased in the source area (MW-8), but increased or remained the same in the remaining wells.

The decrease in benzene concentration at well MW-8, located directly west of the former UST location, from 410 µg/L in April 1995 to 10.4 µg/L in April 2001, indicates either a shift in the dissolved benzene plume, or that natural attenuation processes are occurring and acting to control the extent of the benzene plume in the vicinity of MW-8.

Increases in benzene concentrations at wells MW-5, MW-6, and MW-7, located directly downgradient of the source area, indicates a continuing source of benzene in the AGE source area (residual LNAPL) similar to that observed for total BTEX (Figure 3). However, unlike total BTEX, benzene was not detected in the downgradient peripheral wells MW-15 or MW-16. As such, the benzene plume has not expanded laterally to the same extent as the total BTEX plume.

2.5 Naphthalene in Groundwater

Naphthalene also was analyzed as part of the April 2001 sampling event, and results are presented in Table 3. The extent of naphthalene detected in groundwater is shown on Figure 4, and is less than that of total BTEX (Figure 3). This is likely due to the higher affinity of naphthalene for sorption (retardation) relative to the BTEX compounds. Naphthalene was not analyzed for in the EE/CA, therefore, changes in concentration of naphthalene cannot be evaluated.

2.6 Trimethylbenzenes in Groundwater

TMBs also were analyzed as part of the April 2001 sampling event, and results are presented in Table 3. TMBs are water-soluble fuel constituents considered to be recalcitrant to biological degradation under anaerobic conditions. Therefore, they are commonly used as tracer compounds to calculate BTEX degradation under anaerobic conditions. Concentrations of total TMBs increased over time in groundwater at one location, monitoring point MW-3, close to the source area. Total TMB concentrations decreased or remained the same from the April/July 1995 to the April 2001 in all other monitoring wells sampled. Trends in TMB concentrations at individual wells do not correlate well with the BTEX concentrations, possibly because they are more recalcitrant to biodegradation.

2.7 Inorganic Chemistry and Geochemical Indicators of Biodegradation

As discussed in the 1996 EE/CA, microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction-oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at the former AGE fueling facility site are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992).

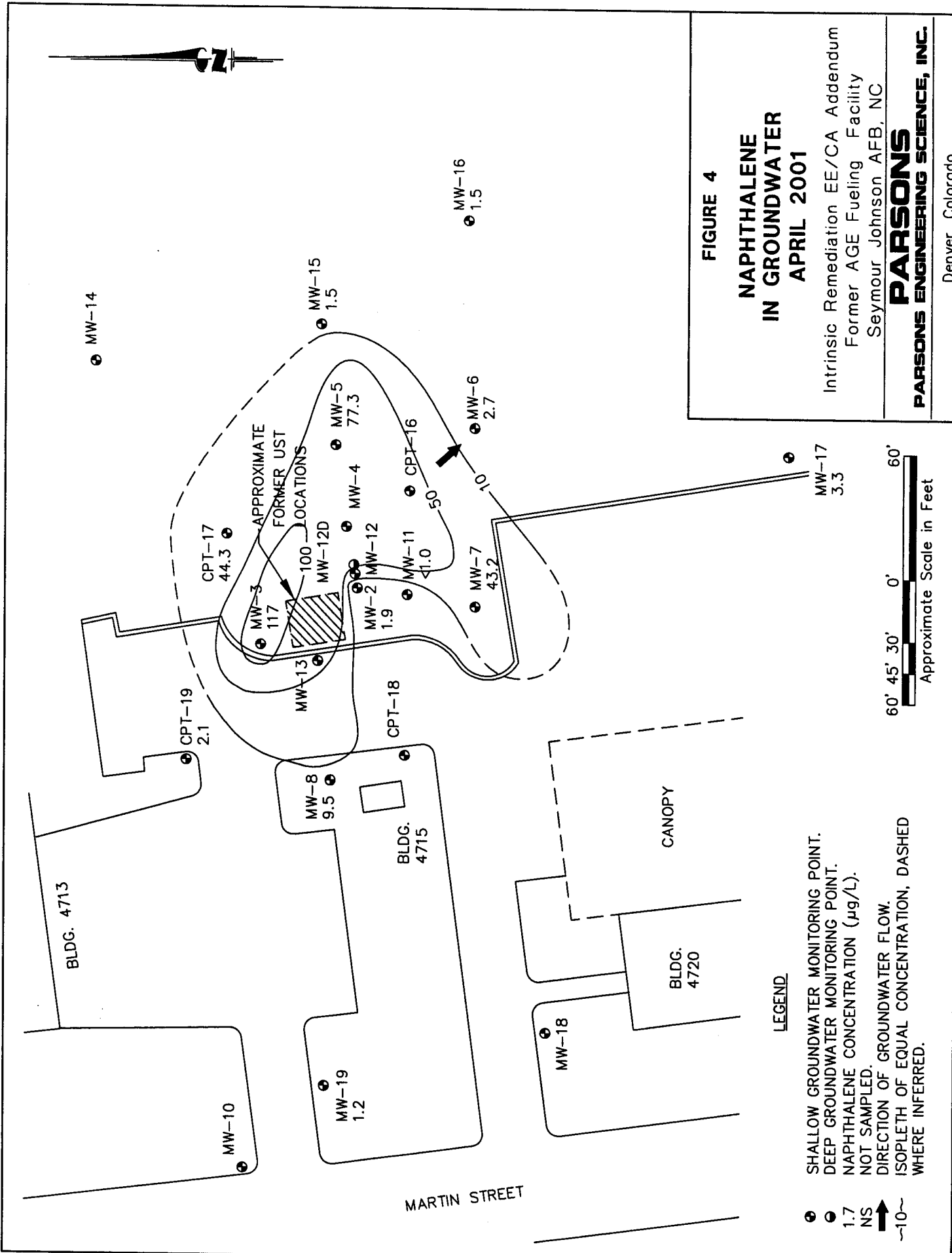


FIGURE 4

**NAPHTHALENE
IN GROUNDWATER
APRIL 2001**

Intrinsic Remediation EE/CA Addendum
Former AGE Fueling Facility
Seymour Johnson AFB, NC

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, manganese, ferric iron hydroxides, sulfate, and carbon dioxide (CO₂). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, manganese, ferric iron (Fe³⁺), sulfate, and CO₂. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron (ferrous iron), and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990).

Data presented in the 1996 EE/CA indicated that biodegradation of fuel hydrocarbons was occurring via both aerobic processes and the anaerobic processes of ferric iron reduction, sulfate reduction, and methanogenesis. Because only low concentrations of nitrate are present in background wells, the process of denitrification is not expected to contribute significantly to the attenuation of BTEX in site groundwater. Geochemical parameters for site groundwater are discussed below. Table 4 summarizes the results of relevant geochemical parameters for the April 2001 sampling event.

Dissolved Oxygen

DO concentrations were measured at 12 of the wells sampled during April 2001 (Table 4). DO concentrations across the site ranged from 0.2 milligrams per liter (mg/L) to 2.3 mg/L. DO concentration isopleth maps for April/July 1995 and April 2001 are presented in Figure 5. Comparison of Figures 3 and 5 shows that areas of elevated dissolved BTEX concentrations correspond to areas of depleted DO concentrations. These lower concentrations of dissolved oxygen indicate that the BTEX compounds at the site are undergoing aerobic degradation.

Comparison of the two isopleth maps, April/July 1995 and April 2001, for dissolved oxygen indicates that dissolved oxygen concentrations are decreasing over time across the site. This implies that aerobic degradation of BTEX compounds is continuing, however, anaerobic degradation processes become more significant as the supply of DO as an electron acceptor is reduced.

Oxidation-Reduction Potential

ORP, a measure of the relative tendency of a solution to accept or transfer electrons, was measured at 12 of the wells sampled in April 2001 (Table 4). The dominant electron acceptor being reduced by microbes during BTEX oxidation is related to the ORP of the groundwater. Isopleth maps of ORP measured at the site in April/July 1995 and April 2001 are presented on Figure 6. The ORPs measured in April 2001 at the site range from -232 millivolts (mV) to 139 mV.

Comparison of Figures 3 and 6 indicates that areas with low ORP generally coincide with areas characterized by high dissolved BTEX concentrations, particularly those areas near the source area. Comparison of ORP values measured in April/July 1995 with those measured in April 2001 (Figure 6 and Table 4) suggests that the ORP of groundwater is decreasing across the site. In 1995, ORP was negative in only one well (MW-6), while in

TABLE 4
GROUNDWATER GEOCHEMISTRY
INTRINSIC REMEDIATION EPCA APPENDIX
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	Date	Temperature (°C) ^a	pH ^b	Conductivity (mS/cm) ^c	Dissolved Oxygen (mg/L) ^d	Redox Potential (mV) ^e	Total Organic Carbon (mg/L)	Nitrate (as Nitrogen) (mg/L)	Nitrite (as Nitrogen) (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Hydrogen Sulfide (mg/L)	Methane (mg/L)	Total Alkalinity (mg/L)	Chloride (mg/L)	Carbon Dioxide (mg/L)
MW-2	10-Apr-01	-	-	-	-	-	15.1	-	<0.10	<0.10	-	14.1	-	<0.009	-	2.31	-
MW-3	18-Apr-95	18.5	5.6	300	1.3	63	-	<0.05 ^f	-	>10	24.2	7.60	0.133	1.92	130	-	>100 ^g
MW-3	10-Apr-01	18.2	5.8	204	0.2	-110	22.9	-	<0.10	0.10	36.0	5.33	0.3	2.59	160	11.2	-
MW-4	18-Apr-95	15.9	5.7	250	0.3	72	-	<0.05 ^f	-	>10	31.6	16.7	0.018	<0.004	80	-	>100
MW-5	18-Apr-95	18.1	5.8	100	1.6	216	-	<0.05 ^f	-	<0.1	1.5	9.00	0.012	0.150	10	-	>100
MW-5	10-Apr-01	16.2	4.8	213	0.6	-101	-	<0.10	<0.10	6.0	9.70	<0.1	0.225	40	44.0	-	
MW-6	17-Apr-95	15.1	5.1	60	0.9	-93	-	-	-	<0.1	2.2	3.90	0.008	0.0350	10	-	100
MW-6	09-Apr-01	18.8	-	74	0.4	-12	16.6	-	<0.10	<0.10	3.0	2.91	<0.1	0.161	20	14.1	-
MW-7	17-Apr-95	17.2	6.1	130	1.2	95	-	-	-	-	9.5	10.20	<0.010	0.0010	40	-	>100
MW-7	09-Apr-01	18.9	-	131	0.2	-174	24.2	-	<0.10	<0.10	18.0	7.13	<0.1	0.0893	40	15.4	-
MW-8	18-Apr-95	17.6	6.0	90	1.0	102	-	<0.05 ^f	-	0.3	5.6	6.10	0.014	2.70	15	-	>100
MW-8	09-Apr-01	17.9	-	86	0.3	-215	3.77	-	<0.10	<0.10	8.0	8.98	0.4	0.642	40	10.6	-
MW-10	17-Apr-95	21.2	5.9	70	8.3	136	-	-	-	<0.1	1.4	9.80	<0.010	<0.004	15	-	26
MW-11	17-Apr-95	18.2	6.9	270	0.2	34	-	-	-	>10	23.2	10.6	0.056	0.200	130	-	>100
MW-11	10-Apr-01	23.5	6.0	236	0.4	-41	19.5	-	<0.10	0.19	30.0	3.67	0.3	1.22	120	8.36	-
MW-12D	18-Apr-95	17.1	8.8	70	0.2	153	-	-	-	0.60	5.0	1.00	<0.010	0.130	20	-	>100
MW-14	10-Jul-95	20.0	5.1	-	6.2	312	-	<0.05 ^f	-	-	0.1	11.8	-	<0.004	-	-	-
MW-15	10-Jul-95	19.0	5.1	-	6.9	232	-	0.100	-	-	0.4	44.1	-	<0.004	-	-	-
MW-15	10-Apr-01	19.3	5.0	68	0.8	37	7.80	-	<0.10	<0.10	0.2	2.82	<0.1	0.017	40	12.8	-
MW-16	10-Jul-95	22.0	5.0	-	3.9	203	-	<0.05 ^f	-	-	1.3	28.9	-	0.142	-	-	-
MW-16	01-Apr-01	20.8	5.0	50	2.3	103	12.8	-	<0.10	<0.10	0.5	3.13	<0.1	<0.009	20	6.43	-
MW-17	10-Jul-95	22.5	5.0	-	1.8	204	-	0.360	-	-	0.1	33.6	-	0.0060	-	-	-
MW-17	09-Apr-01	21.3	-	56	0.6	139	1.70	-	0.21	<0.10	0.4	1.94	<0.1	0.0810	20	8.06	-
MW-18	10-Jul-95	23.0	5.0	-	4.4	278	-	1.700	-	-	<0.1	47.0	-	<0.004	-	-	-
MW-19	10-Jul-95	23.0	5.1	-	1.3	140	-	0.076	-	-	0.8	19.3	-	0.0460	-	-	-
MW-19	09-Apr-01	-	5.0	56	0.4	116	20.5	-	<0.10	<0.10	0.6	12.0	<0.1	0.0448	20	3.28	-
CFT-16	17-Apr-95	18.7	6.8	220	3.3	23	-	-	-	5.0	16.3	4.20	0.013	0.0370	95	-	>100
CFT-16	10-Apr-01	-	-	-	-	-	-	-	-	-	-	-	-	<0.009	-	-	-
CFT-17	18-Apr-95	15.2	6.7	70	0.5	70	-	<0.05 ^f	-	0.10	4.4	0.70	0.316	0.120	20	-	>100
CFT-17	10-Apr-01	16.1	5.3	82	0.3	-232	-	-	<0.10	<0.10	4.0	2.50	4.0	0.773	20	13.5	-
CFT-18	18-Apr-95	16.7	5.9	170	0.7	81	-	<0.05 ^f	-	>10	18.1	4.30	0.053	0.150	80	-	>100
CFT-19	18-Apr-95	16.6	5.6	50	9.1	154	-	0.058	-	0.10	2.3	12.5	0.034	<0.004	10	-	35
CFT-19	10-Apr-01	19.0	5.1	74	0.3	-152	11.1	-	<0.10	0.11	1.5	16.9	0.3	0.0318	20	2.24	-

^a °C = degrees Celsius.

^b su = standard units.

^c mS/cm = microsiemens per centimeter

^d mg/L = milligrams per liter.

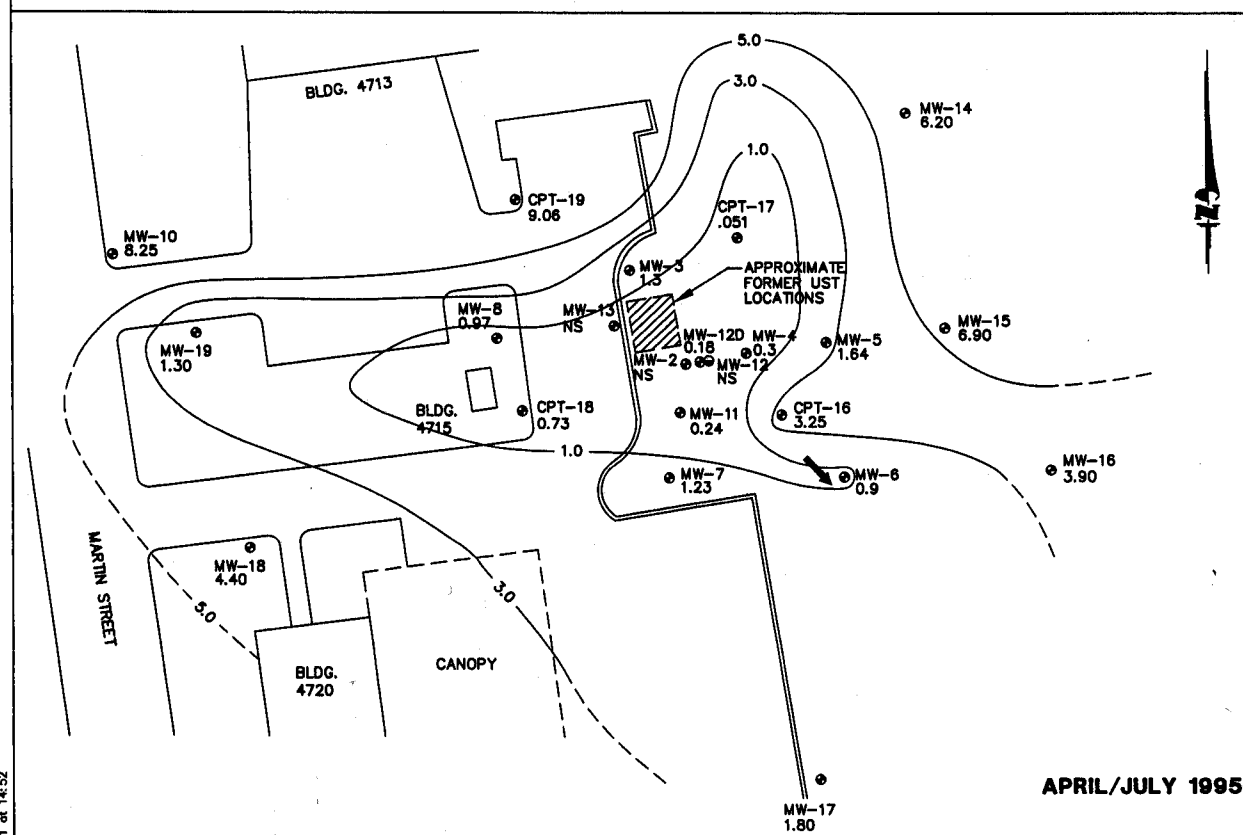
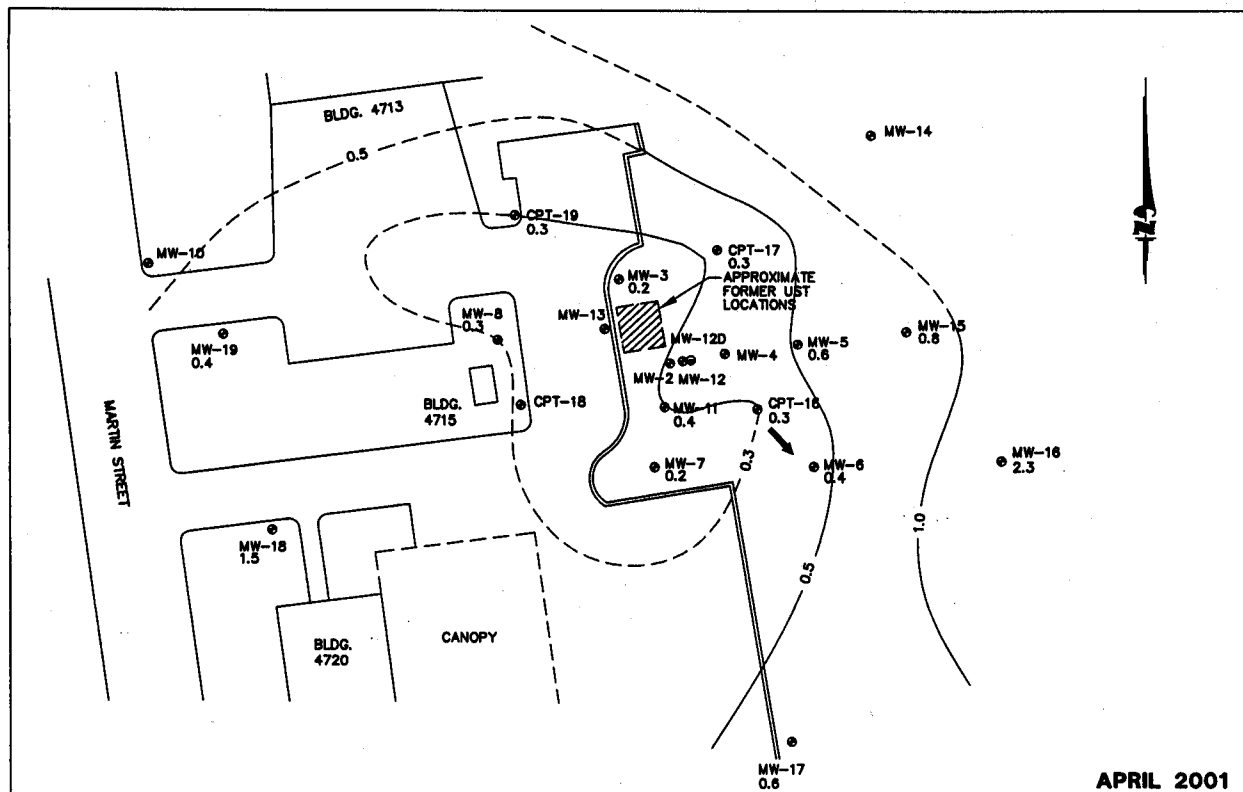
^e mV = millivolts

^f < = analyze not detected above the method detection limit.

^g > = analyze detected above the indicated method detection limit.

^h - = not analyzed.

^a °C = degrees Celsius.
^b mV = millivolts.
^c < = analyte not detected above the method detection limit.
^d > = analyte detected above the indicated method detection limit.
^e - = not analyzed.
^f µS/cm = microsiemens per centimeter.
^g mg/L = milligrams per liter.



S:\ES\cod\733936\ORDM0127.dwg, 06/08/01 at 14:52

-81-

- LEGEND**
- SHALLOW GROUNDWATER MONITORING POINT.
 - DEEP GROUNDWATER MONITORING POINT.
 - NS NOT SAMPLED.
 - 0.24 DISSOLVED OXYGEN CONCENTRATION (mg/L).
 - 3.0- LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L) (DASHED WHERE INFERRED).
 - DIRECTION OF GROUNDWATER FLOW.

60' 45' 30' 0' 60'

Approximate Scale in Feet

FIGURE 5

DISSOLVED OXYGEN ISOPLETH

MAP FOR GROUNDWATER

APRIL/JULY 1995 AND APRIL 2001

Intrinsic Remediation EE/CA Addendum
Former AGE Fueling Facility
Seymour Johnson AFB, NC

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

groundwater environment within the BTEX plume that is favorable for biodegradation by the April 2001 ORP was negative in 7 wells. These results are indicative of a more reducing anaerobic processes of denitrification, iron reduction, sulfate reduction, and methanogenesis. The site wide decrease in ORP suggests that anaerobic degradation processes are likely more significant than aerobic degradation processes in reducing BTEX mass.

Nitrate + Nitrite

Nitrate + nitrite (as nitrogen) concentrations were measured in 13 of the wells sampled during the April 2001 sampling event and are summarized in Table 4. All concentrations were below detection limits. Due to the low concentrations of nitrate + nitrite (as nitrogen) on a site wide basis, it can be concluded that denitrification is not an important degradation process at this site.

Ferrous Iron

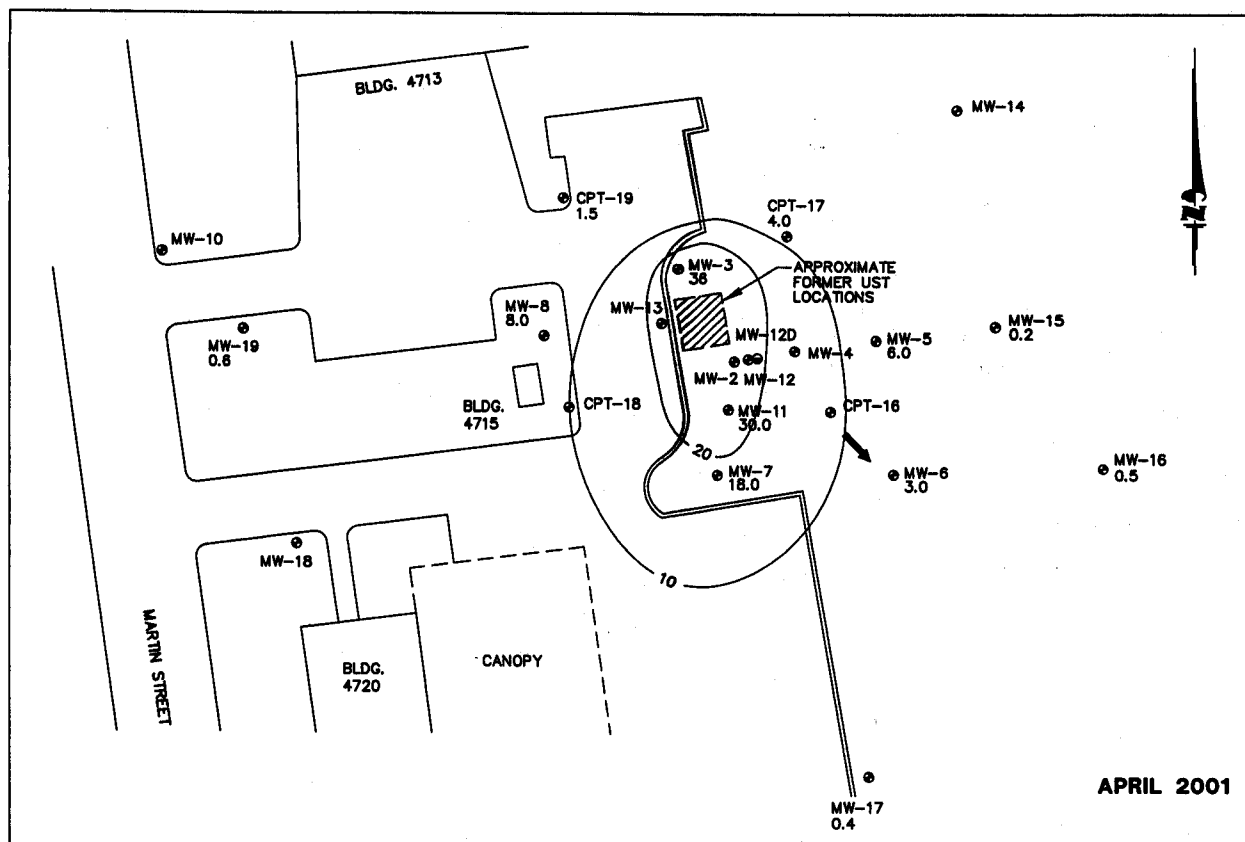
Ferrous iron (Fe^{2+}) concentrations were measured in 12 samples collected during April 2001 and are summarized in Table 4. Concentrations of Fe^{2+} measured at the site during April 2001 range from 0.2 mg/L to 36 mg/L. Accumulation of Fe^{2+} in groundwater indicates that a microbially assisted process is or has occurred recently. Fe^{2+} concentration isopleth maps for April/July 1995 and April 2001 are presented in Figure 7.

Comparison of Figure 3 and 7 indicates that areas of elevated dissolved BTEX concentrations correspond to areas of elevated Fe^{2+} concentrations. The highest Fe^{2+} concentrations measured in April 2001 were at monitoring point MW-3 (36 mg/L) and MW-11 (30 mg/L). These elevated Fe^{2+} detections correspond with the two highest BTEX concentrations measured in April 2001. Background concentrations of Fe^{2+} for wells without detectable concentrations of BTEX in 1995 ranged from 0.05 mg/L to 2.26 mg/L. The elevated Fe^{2+} concentrations within the BTEX plume indicates that iron reduction is an important BTEX degradation process at the site.

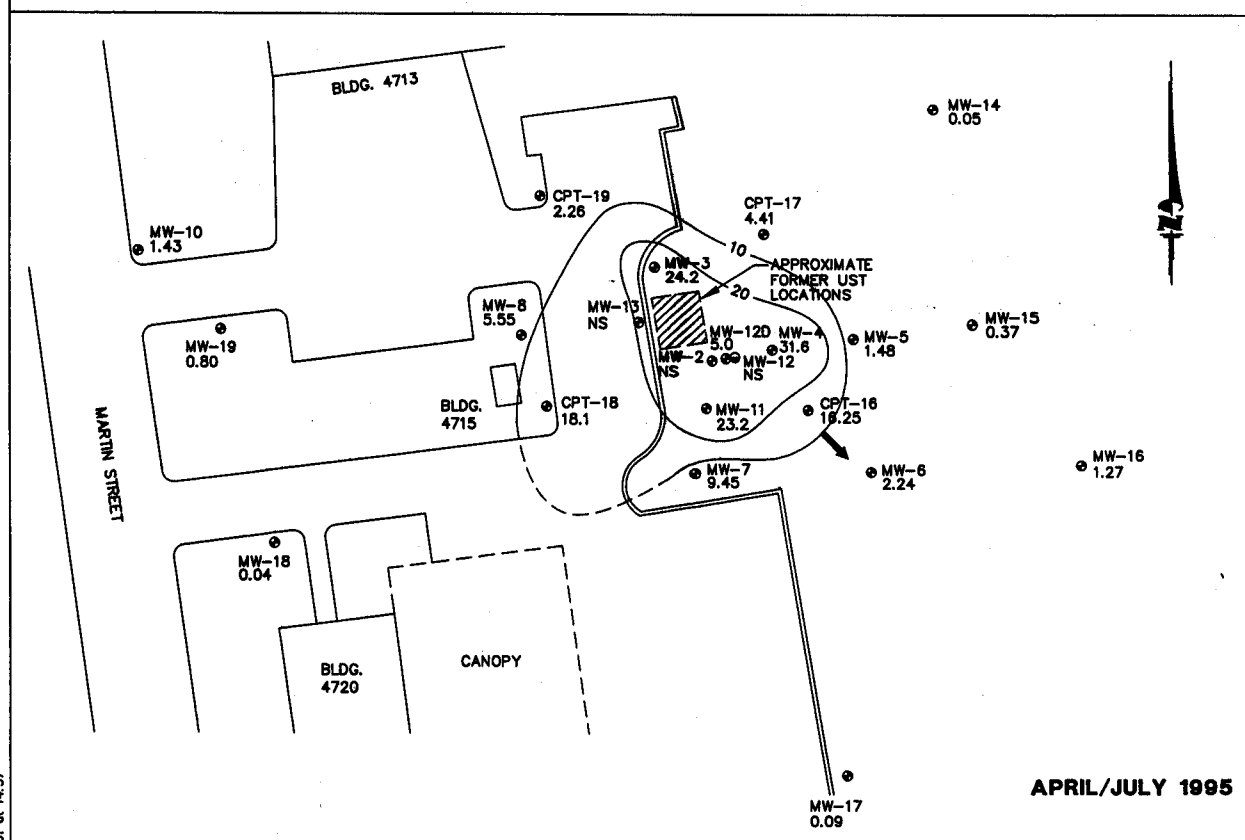
Sulfate

Sulfate concentrations measured during the April 2001 sampling event are presented in Table 4. Concentrations of sulfate measured at the site during April 2001 ranged from 1.94 mg/L to 16.9 mg/L. Sulfate concentration isopleth maps for April/July 1995 and April 2001 are shown on Figure 8. Comparison of Figures 3 and 8 shows that the areas with the highest total BTEX concentrations generally have depleted sulfate concentrations. The correlation of depleted sulfate concentrations with the highest BTEX concentrations provides evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of sulfate reduction.

Background concentrations of sulfate have been estimated at 40 mg/L as stated in the EE/CA. The highest measured sulfate concentration at the site in April 2001 was 16.9 mg/L which is below background concentration. This site wide trend of lower sulfate concentrations is strong evidence that BTEX is being degraded by sulfate reduction. It is also important to note that sulfate concentrations across the site have decreased around the periphery of the BTEX plume.



APRIL 2001



APRIL/JULY 1995

LEGEND

- SHALLOW GROUNDWATER MONITORING POINT.
- DEEP GROUNDWATER MONITORING POINT.
- 4.41 FERROUS CONCENTRATION (mg/L).
- NS NOT SAMPLED.
- DIRECTION OF GROUNDWATER FLOW.
- 10- LINE OF EQUAL FERROUS IRON CONCENTRATION (mg/L) (DASHED WHERE INFERRED).

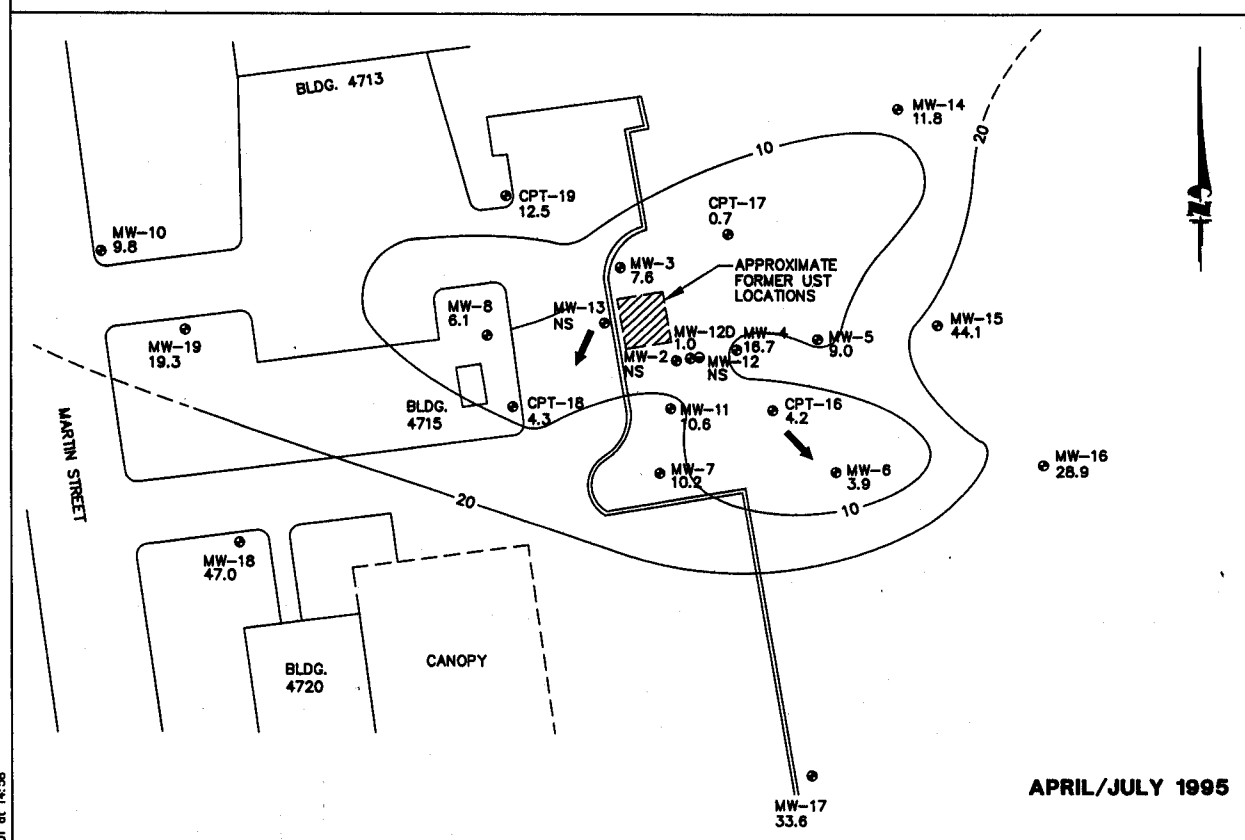
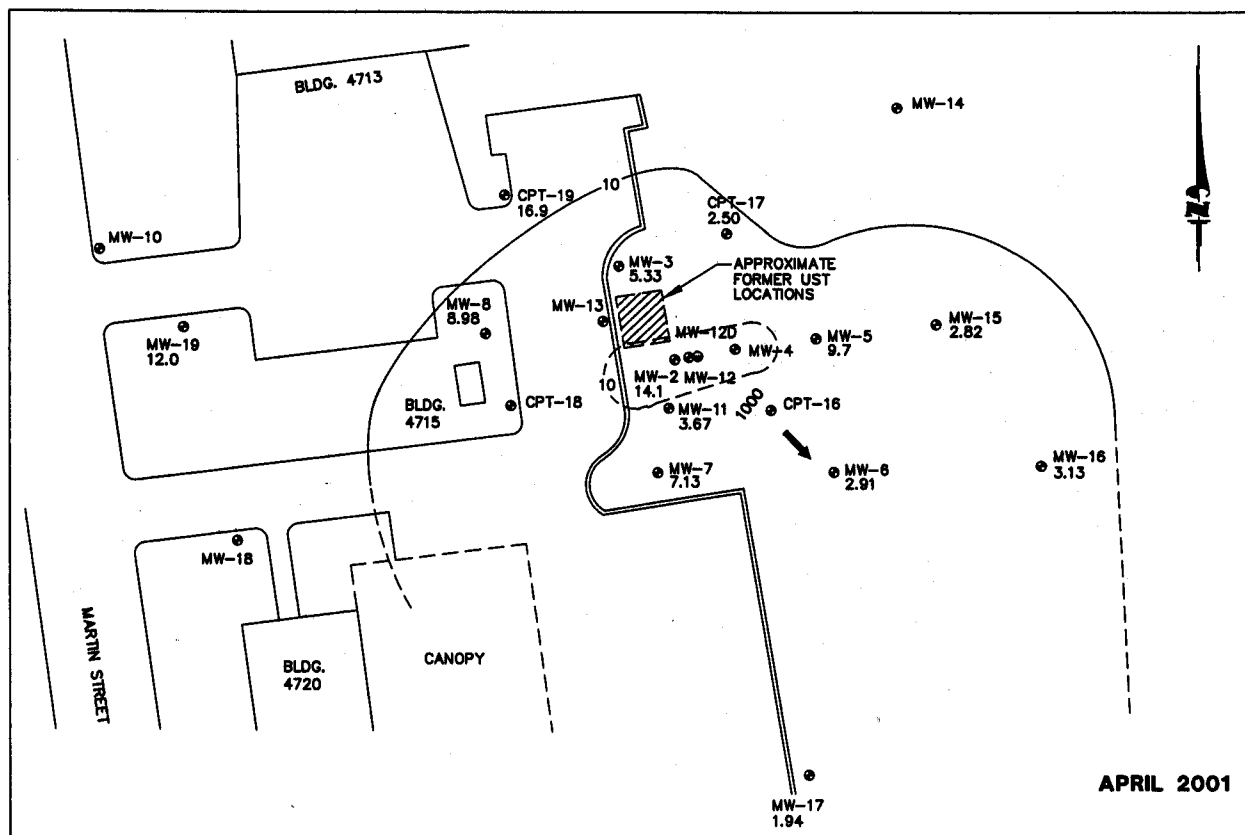
60' 45' 30' 0' 60'
Approximate Scale in Feet

FIGURE 7
FERROUS IRON ISOPLETH
MAP FOR GROUNDWATER
APRIL/JULY 1995 AND APRIL 2001

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LEGEND

- SHALLOW GROUNDWATER MONITORING POINT.
 ● DEEP GROUNDWATER MONITORING POINT.
 6.1 SULFATE CONCENTRATION (mg/L).
 NS NOT SAMPLED.
 -10- LINE OF EQUAL SULFATE CONCENTRATION,
 (mg/L) (DASHED WHERE INFERRED).
 ➡ DIRECTION OF GROUNDWATER FLOW.

60' 45' 30' 0' 60'

Approximate Scale in Feet

FIGURE 8
SULFATE ISOPLETH
MAP FOR GROUNDWATER
APRIL/JULY 1995 AND APRIL 2001

**Intrinsic Remediation EE/CA Addendum
Former AGE Fueling Facility
Seymour Johnson AFB, NC**

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Denver, Colorado

Methane

During methanogenesis, an anaerobic biodegradation process, CO_2 (or acetate) is used as an electron acceptor and methane is produced. The presence of methane in groundwater is indicative of strongly reducing conditions and microbial degradation of fuel hydrocarbons. Methane concentrations in groundwater are listed in Table 4, and methane concentration isopleth maps for April/July 1995 and April 2001 are presented on Figure 9. Concentrations of methane measured at the site during April 2001 range from <0.0009 mg/L to 2.59 mg/L. Comparison of Figures 3 and 9 shows that the areas with elevated BTEX concentrations lie within areas of elevated methane concentrations.

Although the methane concentrations observed in April 2001 are lower than observed during April/July 1995, the concentrations are still above background levels. The relatively high concentration of methane across the site suggest that anaerobic conditions exist within the BTEX plume. This correlation provides strong evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of methanogenesis.

Alkalinity

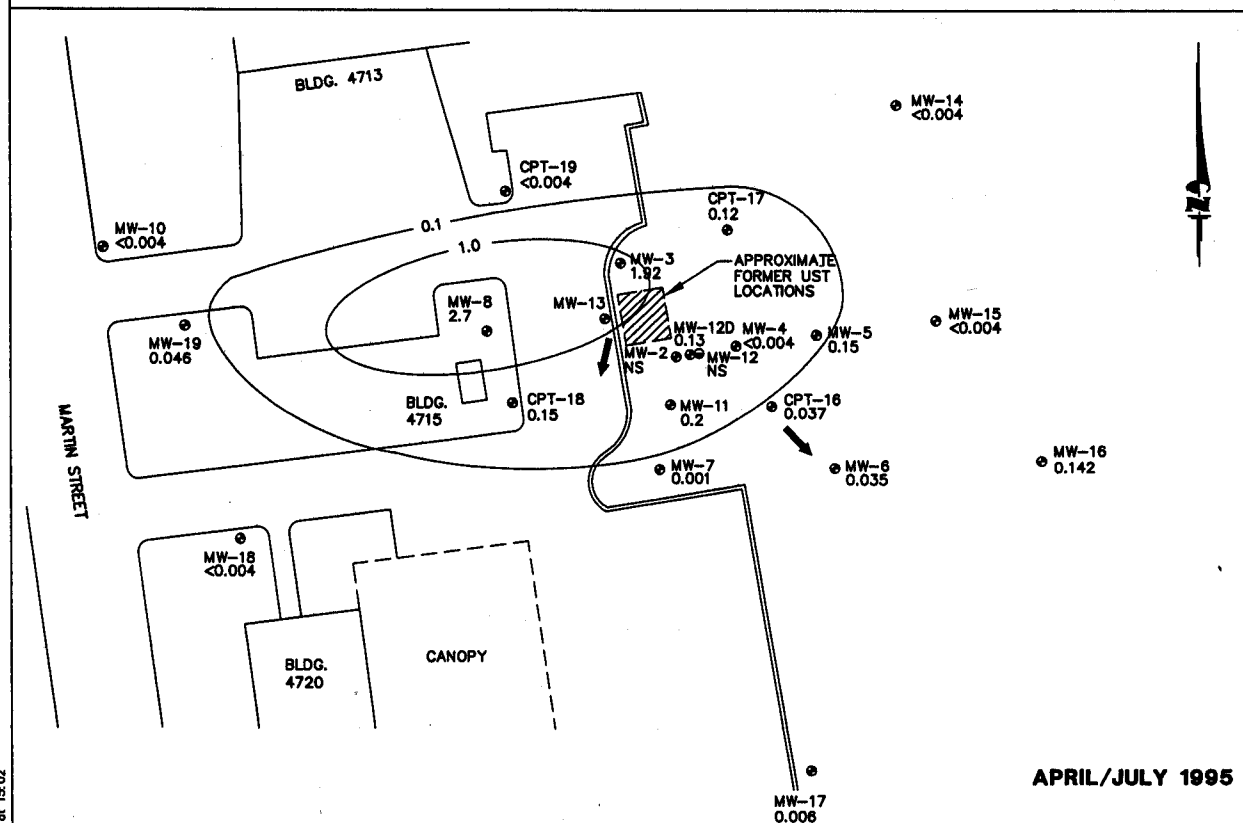
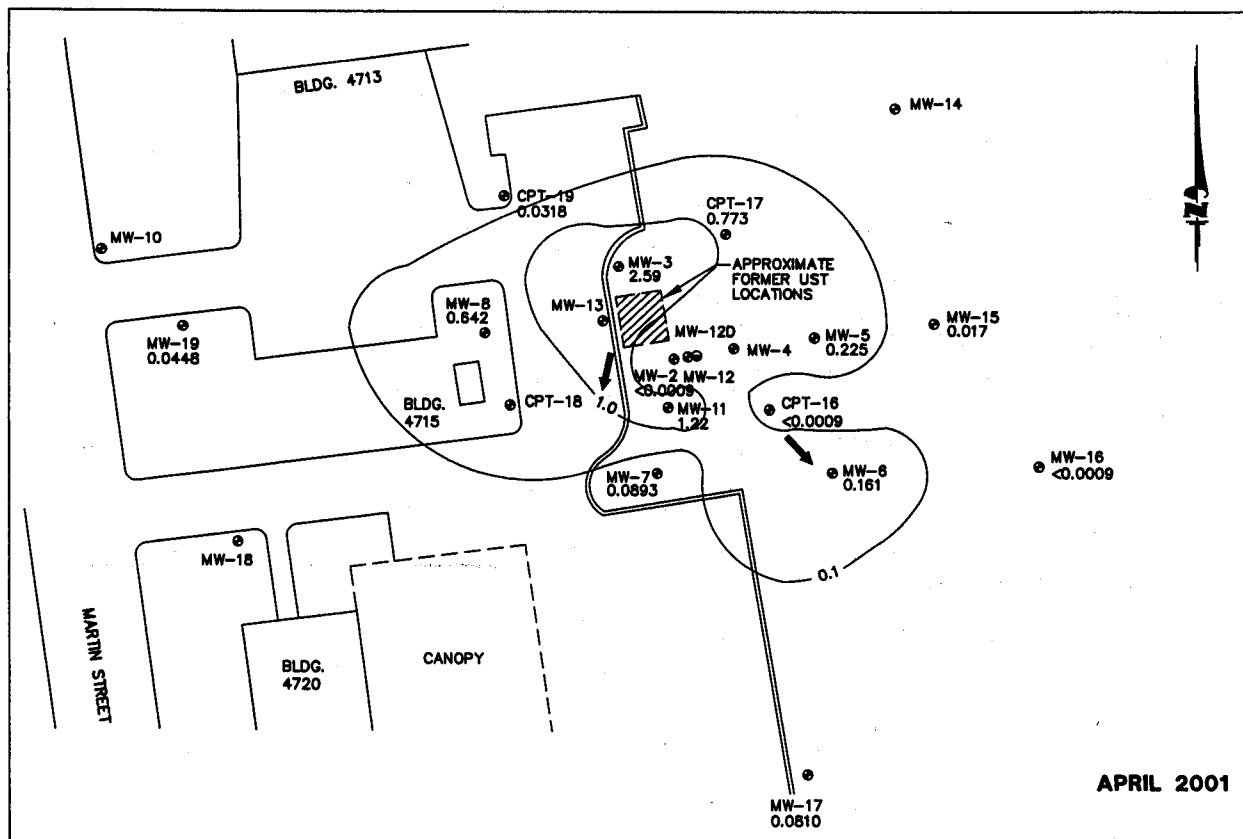
Alkalinity is a measure of the ability of water to buffer changes in pH, and can be used as an indicator of biodegradation of BTEX. Biodegradation of BTEX produces carbon dioxide which, when mixed with water in the proper conditions, produces carbonic acid. In aquifers that have carbonate minerals as part of the matrix, carbonic acid dissolves these minerals, increasing the alkalinity of the groundwater. Therefore, an increase in alkalinity can be observed in areas of active biodegradation of fuel hydrocarbons. Total alkalinity [measured as calcium carbonate (CaCO_3)] of groundwater samples collected at the site from April/July 1995 and April 2001 are summarized in Table 4. There is no significant difference in alkalinity of groundwater between the April/July 1995 and April 2001 sampling events. As stated in the EE/CA, alkalinity at this site is in the low to moderate range for groundwater. As such, it is possible that rapid changes in pH may have an impact on microbial degradation of BTEX.

pH

pH was also measured for groundwater samples collected in April 2001 and is summarized in Table 4. The optimal pH range for BTEX-degrading microbes is between 6 and 8 standard units (su). In April 2001, the pH for one of the groundwater samples collected at the site (MW-11) was within the optimal pH range with a pH of 6.0. All other wells sampled in April 2001 were lower than the optimal range. The pH of groundwater at the AGE Site measured in April 2001 dropped slightly since the April/July 1995 sampling event. At lower pH, biodegradation rates may be slower than at the optimal pH range, but biodegradation may still occur.

Temperature

The temperature of groundwater measured at the site in April 2001 is summarized in Table 4. Temperature affects the type and growth rates of bacteria that can be supported in the groundwater environment. Groundwater temperatures at the site ranged from 16.1



-24-

LEGEND

● SHALLOW GROUNDWATER MONITORING POINT.
 ● DEEP GROUNDWATER MONITORING POINT.
 1.92 METHANE CONCENTRATION (mg/L).
 NS NOT SAMPLED.
 -0.1 ~ LINE OF EQUAL METHANE CONCENTRATION (mg/L)
 (DASHED WHERE INFERRED).
 ➡ DIRECTION OF GROUNDWATER FLOW.

60' 45' 30' 0' 60'

Approximate Scale in Feet

FIGURE 9

**METHANE ISOPLETH MAP
FOR GROUNDWATER
APRIL/JULY 1995 AND APRIL 2001**

**Intrinsic Remediation EE/CA Addendum
Former AGE Fueling Facility
Seymour Johnson AFB, NC**

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degrees Celsius (°C) (CPT-17) to 23.5 °C (MW-11). These moderately warm groundwater temperatures are sufficient to sustain bacterial growth and suggest that bacterial growth should not be inhibited.

3.0 CONCLUSIONS AND RECOMMENDATIONS

LNAPL continues to persist as a source of fuel hydrocarbons in groundwater at the AGE Site. The thickness of the free product layer has decreased at the upgradient edge of the source area (MW-13); however, the extent of the free product plume has migrated slightly and expanded in the downgradient direction. Free product was identified for the first time during the April 2001 sampling event in downgradient wells MW-4, MW-7, and MW-11.

Results of groundwater monitoring conducted from 1995 to 2001 indicate that natural attenuation of BTEX continues at the AGE Site. Based on the 10 µg/L concentration isopleth for total BTEX, the extent of the BTEX plume has been stable since the last sampling event in April 1995 (Figure 3). However, low concentrations of BTEX (less than 10 µg/L have been detected in peripheral wells MW-19, CPT-19, MW-15, MW-16, and MW-17 for the first time in April 2001, suggesting low level expansion of the BTEX plume.

The maximum BTEX concentration detected at the site from wells not containing free product LNAPL has decreased from 13,800 µg/L at well MW-4 in April 1995 to 2,180 µg/L at well MW-11 in April 2001. BTEX concentrations at well MW-11 did demonstrate a significant decrease from 8,620 µg/L in 1995.

In general, BTEX concentrations in wells to the west and within the source area (MW-8, MW-11, and MW-7) have decreased, while wells to the north, south, and east of the source area have increased. The decrease of BTEX concentration at those wells within the plume may be the result of changes in the direction of groundwater flow, and/or microbially mediated natural biodegradation of the contaminants at the AGE Site. The location of relative changes in BTEX concentrations indicates that the direction of plume migration has shifted towards the east-southeast, likely a result of slight changes in the direction of groundwater flow. The presence of LNAPL at well MW-4 indicates a slight migration of the LNAPL plume towards the east-southeast as well.

Geochemical indicators continue to support the occurrence of natural biodegradation at the site as evidenced by the distribution of electron acceptors and metabolic byproducts that are involved in biologically mediated redox reactions. The April 2001 geochemical data indicate the groundwater environment within the BTEX plume is more reducing than in 1995, and the anaerobic processes of iron reduction, sulfate reduction, and methanogenesis continue to be destructive attenuation mechanisms. Due to naturally low levels of nitrate both within and outside of the BTEX plume, denitrification does not appear to be a significant process at the site.

Comparison of the observed BTEX plume with simulated BIOPLUME II model plumes presented in the Final EE/CA indicates the models are not representative of current site conditions. The simulated BTEX plume for no source reduction (Model

SETUP16) predicts that total BTEX concentrations will remain above 12,000 µg/L indefinitely. The maximum BTEX concentration observed in 2001 was 2,180 at well MW-11. The simulated BTEX plume for total source reduction over 5 years (Model SR5) predicts that total BTEX concentrations will decrease to 3,000 µg/L by 2002, with some expansion of the BTEX plume. While this is similar to the observed 2001 BTEX plume, the continued presence of LNAPL at the site is not duplicated in the model, as the total source is simulated to be removed by 2010. A reasonable rate of natural source weathering was not accounted for in the model SETUP16 predictions. The similarity of current conditions to Model SR5 conditions suggests that the rate of natural weathering of the source and biodegradation of dissolved contamination is significant. Although a continuing source (LNAPL) persists at the AGE Site, natural attenuation alone has controlled and limited the migration and expansion of the BTEX plume.

Continued long-term monitoring is recommended to evaluate the evolution of the BTEX plume and the ability of natural attenuation, microbially mediated biodegradation in particular, to further stabilize and ultimately attenuate this plume. Annual groundwater monitoring is a sufficient frequency based on the overall stability of the BTEX plume. Based on the detection of total BTEX in the downgradient wells MW-15, MW-16, and MW-17, additional downgradient well locations should be considered to evaluate potential future expansion of the plume. Finally, free product at the site should be sampled and analyzed for BTEX and naphthalene. Results of this sampling could be used with earlier sampling results to calculate a natural source weathering rate. A natural source weathering rate would allow for more accurate predictions of the persistence of the BTEX plume.

4.0 REFERENCES

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- Law Environmental, Inc., 1992, *Final Remedial Investigation Report for Site ST-01, SD-02, SD-03, SS-04 and ST-05 (Sites 14 and 15), Seymour-Johnson Air Force Base, North Carolina*. Prepared for U.S. Army Corps of Engineers Omaha District, Contract No. DACW45-89-DO5000.
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APPENDIX A
ANALYTICAL RESULTS
APRIL 2001

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.

Environmental Science

In reply refer to: 01-MB28
Contract Number: 68-C-98-138

To Roger Cosby
Garmon Smith

From: Mark Blankenship

Thru Dr. Caplinger
Lisa Black
Dr. Huang

Date: #####

Subject SF-2-347-1

Originator: Dr. Kampbell

Copies: Dr. Kampbell
Lisa Black

ANALYSIS CODE

Sample Site: Seymour-Johnson AFB
Date Collected: 4/9-10/01
Date Received: 4/16/01
Date Analyzed: 5/4/01

Service Station N/A
ManTech Sample Set: 248
Analysis Type: GC Purge and Trap
Sample Preparation: N/A
Number of Samples: 14

SOP Number: RSKSOP-122 Rev.1

*Analysis of Volatile
Aromatic

All sample(s),
blank(s), and

ANALYSIS CODE

If you have any
questions, please

Table 1. Quantitative Report										
Sample Site: Seymour-John						Service Request		SF-2-347-1		
Date Collected: 4/18/01						Originator		Dr. Kampbell		
Date Received: 4/18/01						Analyst		Mark		
Date Analyzed: 5/4/01						Analysis Type		Partnership		
ManTech Sample Set 248						Service Station:		WPA Trap		
						Number of Samples		14		

m-NAPHTHALENE
86.9
ND
BLQ
22.4
26.6
2.1
8.7
5.8
3.7
BLQ
BLQ
BLQ
BLQ
BLQ
83.3
7.8
1.0
100

Seymour-Johnson AFB

Well	Date	TOC	Redox	Cond.	DO	Temp.	pH	Fe ²⁺	Alkalinity	H ₂ S
		ft	mV	μs/cm	mg/L	°C		mg/L	mg/L	mg/L
AGE Site										
MW-19	4/9/01	11.01	116	55.7	0.4	-	5.0	0.6	20	<0.1
MW-17	4/9/01	12.11	139	55.5	0.6	21.3	-	0.4	20	<0.1
MW-16	4/9/01	12.10	103	49.6	2.3	20.8	5.0	0.5	20	<0.1
MW-6	4/9/01	11.95	-12	74.2	0.4	18.8	-	3.0	20	<0.1
MW-8	4/9/01	10.30	-215	86.3	0.3	17.9	-	8.0	40	0.4
MW-7	4/9/01	12.34	-174	131.0	0.2	18.9	-	18.0	40	<0.1
CPT-17	4/10/01	9.84	-232	82.0	0.3	16.1	5.3	4.0	20	4.0
MW-5	4/10/01	11.20	-101	213.0	0.6	16.2	4.8	6.0	40	<0.1
CPT-19	4/10/01	9.09	-152	74.0	0.3	19.0	5.1	1.5	20	0.3
MW-15	4/10/01	13.05	37	68.0	0.8	19.3	5.0	0.2	40	<0.1
MW-2	4/10/01	No yield								
MW-11	4/10/01	11.45	-41	236	0.4	23.5	6.0	30.0	120	0.3
CPT-16	4/10/01	No yield								
MW-3	4/10/01	8.69	-110	204	0.2	18.2	5.8	36.0	160	0.3
SWMU87 Site										
MW-8	4/11/01	-	-70	474	0.6	18.6	4.6	20.0	20	0.8
MW-3	4/11/01	-	36	114	1.1	18.2	-	0.8	20	<0.1
MW-12	4/11/01	-	65	296	0.3	18.9	4.7	9.0	40	<0.1
AGE Site										
		<u>Product(ft)</u>	<u>Water(ft)</u>							
MW-4		11.15	12.40							
MW-12		11.4	11.41							
MW-3		ND	8.69							
MW-13		8.79	8.91							
MW-2		ND	9.69							

Field Site Measurements

Don Rumphell

Sample Site: Seymour-Johnson AFB
Date Collected: 4/9/01
Date Received: 4/16/01
Date Analyzed: 4/18/01
Service Request: SF-2-347/0
Samples Analyzed: 13

Service Station: not applicable
ManTech Sample Set: 248
Analysis Type: Headspace/aq/GC
Sample Preparation: not applicable
Originator: Dr. Don Kampbell
Analyst: Lisa Hudson

Sample	Methane ppm, V/V gas	Methane mg/L in water
100 ppm CH4	110	~
Helium Blank	n.d.	~
H2O Blank	~	n.d.
MW-2	~	BLS
MW-3	~	2.59
MW-5	~	0.225
MW-6	~	0.161
MW-7	~	0.0893
MW-7 Lab Dup	~	0.0894
10 ppm CH4	10.2	~
MW-8	~	0.642
MW-11	~	1.22
MW-15	~	0.0173
MW-16	~	n.d.
MW-17	~	0.0810
MW-17 Lab Dup	~	0.0804
MW-19	~	0.0448
CPT-17	~	0.773
CPT-19	~	0.0318
10 ppm CH4	9.88	~
100 ppm CH4	107	~
1000 ppm CH4	1,100	~
10,000 ppm CH4	10,100	~
Lowest Standard	10.0	0.0009

Units for the samples are mg/L dissolved in water.

Units for the standards are parts per million, V/V in gas phase.

~ denotes not applicable

n.d. denotes not detected

BLS denotes below lowest calibration standard

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.

Environmental Science

In reply refer to: 01-LP53
Contract Number: 68-C-98-138

To: Mr. R. Cosby
Mr. G. Smith

From: Ms. L. Pennington

Thru: Ms. L. Black
Dr. J. Caplinger
Dr. F. Huang

Date: May 8, 2001

Subject: SF-2-347/1

Originator: Dr. D. Kampbell

Copies: Dr. D. Kampbell
Ms. Lisa Black

Sample Site: Seymour-Johnson
Date Collected: 4/8 to 4/10/01
Date Received: 4/16/01
Date Analyzed: 4/26 to 4/30/01
Number of Samples: 13

Service Station: N/A
ManTech Sample Set: 248
Analysis Type: Inorganics
Sample Preparation: N/A

Methods Used:

<i>Parameter</i>	<i>Method</i>
Nitrite + Nitrate	Lachat FIA 10-107-04-2-A
Ammonia	Lachat FIA 10-107-06-1-A
Chloride	Waters Capillary Electrophoresis N-601
Sulfate	Waters Capillary Electrophoresis N-601
Quality Control	RSKSOP-214, revision 0 - Quality Control Procedures for Inorganic Analyses Using Waters Capillary Electrophoresis, Lachat Flow Injection Analyses, and Mettler DL21 Autotitration

Quality control measures performed along with your samples included analysis of blanks, spikes, duplicates, check standards and known ERA samples as outlined in RSKSOP-214, revision 0. If you have any questions concerning this data, please feel free to contact me.

Table 1. Quantitative Report

Sample Site: Seymour-Johnson

Date Collected: 4/8 to 4/10/01

Date Received: 4/16/01

Date Analyzed: 4/26 to 4/30/01

Service Station: N/A

Number of Samples: 13

Service Request: SF-2-347/1

Originator: Dr. D. Kampbell

ManTech Sample Set: 248

Analyst: Ms. L. Pennington

Analysis Type: Inorganics

SAMPLE	mg/L NO ₂ ⁻ +NO ₃ ⁻ (N)	mg/L NH ₃ (N)	mg/L Cl ⁻	mg/L SO ₄ ⁻²
MW-2	<0.10	<0.10	2.31	14.1
MW-3	<0.10	0.10	11.2	5.33
MW-5	<0.10	<0.10	44.0	9.70
MW-6	<0.10	<0.10	14.1	2.91
MW-7	<0.10	<0.10	15.4	7.13
MW-8	<0.10	<0.10	10.6	8.98
MW-11	<0.10	0.19	8.36	3.67
MW-15	<0.10	<0.10	12.8	2.82
MW-16	(<0.10) (<0.10)	(<0.10) (<0.10)	6.43	3.13
MW-17	0.21	<0.10	8.06	1.94
MW-19	<0.10	<0.10	3.28	12.0
CPT-17	<0.10	<0.10	(13.5) (13.1)	(2.50) (2.44)
CPT-19	(<0.10) (<0.10)	(0.10) (0.11)	2.24	16.9
BLANK	<0.10	<0.10	<1.00	<1.00
ERA	5.76	5.79	67.0	31.4
ERA True Value	5.39	6.30	66.8	29.8
Check Std.	(0.24) (2.40)	(0.21) (2.56)	5.03	5.14
Check Std. True Value	(0.25) (2.50)	(0.25) (2.50)	5.00	5.00
Spike Recovery	99%	109%	96%	97%

report

Service Request:	SF-2-347	Date Received:	4/16/01
Originator:	Dr. D. Kampbell	Date Analyzed:	5/2/01
Site:	Seymour-Johnson	Analyst:	Kelly Bates
Date Sampled:	?	SOP:	RSKSOP-102
SAMPLE	TOC mg/L		
MW2	15.1		
MW3	22.9		
MW5	0 ←	Broken sample when received	
MW6	16.6		
MW7	24.2		
MW8	3.77		
MW8 SPIKE	26.1	SPIKE RECOVERY: 96.8 %	
MW11	19.5		
MW15	7.80		
MW16	12.8		
MW17	1.70		
MW17 LAB DUP	1.66		
10 STD	9.98		
MW19	20.5		
CPT19	11.1		
CPT17	0 ←	Broken sample when received	
BLANK	< 0.40		